Kinetic Environments:

Explorations into the Spatial Experience of Transformable Surfaces

Chretien Macutay

December 2012

Submitted towards the fulfillment of the requirements for the Doctor of Architecture Degree

School of Architecture

University of Hawai`i

Doctorate Project Committee

Kris Palagi, Chairperson

Jim Dator

Sooyoun Park

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We certify that we have read this Doctorate Project and that, in our opinion, it is satisfactory in scope and quality in fulfillment as a Doctorate Project for the degree of Doctor of Architecture in the School of Architecture, University of Hawai'i at Mānoa.

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CONTENTS

ABSTRACT

This doctoral thesis explores kinetic environments through a narrative of historic definitions cross referenced with analysis of the spatial experiences of transformable surfaces. Research by Rudolph Arnheim and Thomas Thiis-Evensen along with project case studies gives foundation to an argument for investigating the relationship between human perception and kinetic environments. These relationships are understood further through a systematic cataloging and analysis of modeled transformable surfaces, computer generated simulation studies, and prototype proposals for the physical application and testing of kinetic principles. These explorations serve to show that existing definitions of spatial experience are not applicable when considering the potentialities of kinetic surfaces, and thus a refined framework is generated to begin to understand the spatial experience of kinetic environments.

INTRODUCTION

Our foundation for understanding spatial concepts in architecture relies on extensive studies of buildings and structures that are traditionally static. Rather than designing buildings and spaces frozen in time, I am driven to create environments that are inherently kinetic: spaces that understand and react to the user, transforming and adapting to the dynamics of the human condition. When considering this non-static architecture, however, one currently has an out-dated framework to reference. Architectural theories covering spatial perception and experience are fundamentally based on rigidly-immovable environments designed for permanence. These theories for understanding space have validity, yet are only applicable to a built environment that is stationary and long-lasting. In recent years, architects and designers have successfully begun to challenge the dominance of these static spaces through kinetic systems that achieve more efficient function, aesthetics, and sustainability; However, the theoretical framework for understanding space still references theories of static space devoid of movement, and is highly inapplicable when considering kinetic motion. As the design of kinetic systems in our built environment progress with technological advancement, it is unwise for architectural discussion to continually neglect the spatial implications of kinetic movement.

This doctoral thesis explores the spatial implications of kinetic surfaces by formulating an argument against existing spatial definitions. The research begins to generate a new framework for the spatial experience of kinetic environments, and thereby expand the knowledge base of dynamic, non-static spaces. The overarching purpose of this research is to stimulate attention towards this non-static type of architecture, with a subset intention of exploring the potential of these kinetic environments to create unique and complex spatial experiences. Through a narrative of historic definitions cross-referenced with analysis of the spatial experiences of kinetic surfaces, this research will specifically look to address the questions: *Do kinetic surfaces modify ones' perception of space? Do existing spatial definitions still apply when considering the movement of kinetic surfaces? What are the variables of kinetic surfaces that affect spatial experience?* Weaving conducted research in spatial perception and experience by architectural writers Rudolph Arnheim and Thomas Thiis-Evensen along with case study examples and design explorations establishes an argument that answers these questions.

This doctorate project begins by recognizing the concept of surfaces as principle objects key to spatial perception. By applying kinetic principles to surfaces one can begin to understand the initial spatial implications of motion. Extracting kinetic concepts from existing projects and case studies, a catalog of thirty-two physically-transformable surface models was created and analyzed, as a necessary step to understand how to manipulate a singular surface to generate specific spatial expressions. Based on this catalog, a selection of five surfaces that exhibited qualities capable of effectively manipulating spatial experience were decided upon to test in kinetic computer simulations.

Using Rhinoceros 4.0, Grasshopper, and Vray, computer generated simulations of kinetic surfaces were tested to see if the kinetic principles from the selected surfaces in the catalog can modify spatial experience. The first phase of simulations tested these principles against four of Thiis-Evensen's wall forms (concave, convex, lean toward, and lean away). These comparative simulation studies serve to show that existing definitions of spatial experience are not applicable when considering the potentialities of kinetic movement. The second phase of simulations experimented with different kinetic principles applied specifically to the surface in Thiis-Evensen's concave space, as an informative progression towards the design of a first working prototype. The summary at the end of these simulations outline the variables of kinetics that determine, and can be manipulated to alter, ones perception of space.

This study is organized into 7 chapters. Chapter one provides the historic background of spatial perception through the lens of writers Arnheim and Thiis-Evensen and introduces the implications of surface as essential to ones spatial perception and experience in architecture. Chapter two discusses the definition of kinetic environments, the properties of transformability, and the evolution of the projects. Chapter three looks at two case-study projects, the Bengt Starlight Theater and AEGIS Hypo-surface, to highlight issues of spatial experience within kinetic environments. Chapter four contains a catalog and analysis of physically-transformable surface models that explore kinetic principles revealed in chapters two and three. Chapter five takes specific kinetic principles from the catalog into computer simulation studies to challenge the existing spatial definitions established by Thiis-Evensen, establish the variables of kinetic movement that have the potential to alter spatial perception, and to inform the guidelines of designing potential physical prototypes. The proposals and working prototype seen in chapter 6 are created as a preliminary step towards beginning to test the kinetic variables in a tangible and tactile environment. Finally, Chapter 7 contains the conclusion statement, as well as proposals for continuing explorations.

Ultimately, this design-research oriented investigation expresses the importance of relationships between user and space, and recognizes the potential of kinetic environments to provide a dynamically influential spatial experience naturally befitting of our own kinetic nature.

1 SPATIAL EXPERIENCE

Architecture has been extensively studied and perceived as static, permanent structures. Many of the buildings that are considered great architecture are grand structures that still stand in the same place today. The typical study of these static buildings has revealed spatial relationships that architects rely upon and utilize to manipulate perceptions of space within their designs. Our understanding of what spatial relationships are, consequently, founded on a static environment. *But what are the spatial relationships with a building or space that is not static? Do kinetic surfaces modify ones' perception of space? Do existing spatial definitions still apply when considering the movement of kinetic surfaces? What are the variables of kinetic surfaces that affect spatial experience?* In order to answer these questions, one must first understand how we perceive space.

Perception of Space

The idea of spatial perception is a far-reaching concept that can be defined and argued through many different approaches. Spatial perception is inter-linked to physiological, sociological, and psychological factors, each with their own, sometimes conflicting commentaries on how one recognizes the surrounding environment. The ability for a person to establish some sort of spatial orientation and cognition relies not only on sensory inputs, such as auditory, olfactory, and visual cues, but also on the individuals own combination of experiences and needs.[1] It is therefore difficult to establish specific definitions on how one perceives space, as each person understands it in their own unique way. Still, there are general observations that can be made about spatial perception indifferent of individual preconceptions.

It should be indicated as a disclaimer, at this point, that this research focuses particularly on our visual perception of space, and chooses to omit other sensory cues. This omission is not to devalue the importance of smell, sound, and touch in spatial perception, nor to disregard the heavily scientific or sociological implications, but rather is in deference to humans' dominant reliance on vision within a space.

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[1] *Ittelson.* 1960. 12.

It is true that one participates in multiple sensory cues when experiencing a space, but for clarity and to prevent any convolution, any references to spatial perception in this research will be limited to a heavily visual regard. Interestingly, renowned architectural writers like Rudolph Arnheim and Thomas Thiis-Evensen often approached the topic of spatial perception in this manner, which hints at the importance of a visual bias in space perception.

In regards to architectural space, Rudolph Arnheim set the framework for the psychological origin of space perception. He defines space as always present and existing, but experienced only through the interrelation of objects; space perception therefore occurring only in the presence of perceivable things.[2] This idea follows the notion that a space is not an entity that is created, but rather defined and perceived through objects. Although one can imagine, for instance, a construct of being a solitary object suspended in emptiness surrounded by infinite expanse, nothing would be perceived because the lack of a point of reference. Similarly, consider the case of being in a well-lit room that all of a sudden turns "pitch-black": ones perception of space is quickly disrupted as the objects that were once visible become visually indistinguishable from the air around it. The interrelation of objects is vital to our spatial perception; even our understanding and perception of space outside of earth's atmosphere relies on distances, directions, and velocities between objects.

Arnheim believes that space is in no way given by itself but is created by a particular constellation of natural and man-made objects.[3] In architectural discussion, this constellation refers to our environment, as an environment is defined as the circumstances, objects, or conditions by which one is surrounded.[4] Spatial perception and environment therefore go hand in hand: The circumstances, objects, or conditions by which we are surrounded create and constitute our spatial perception. This fundamental concept is the foundation for our understanding and constructing of architectural spaces. It ranges and applies to the spatial framework of whole cities, as well as the spatial understanding of a small room. As a result, architects give a great deal of attention to the positioning, scale, and materiality of objects that

[2] *Arnheim.* 1977. 10.

[3] *Ibid.* 13.

[4] *Merriam-Webster Online,* 2011., s.v. "environment."

compose our natural and man-made environments, as these properties will constitute our spatial framework, perception, and experience.

Surface in Spatial Experience

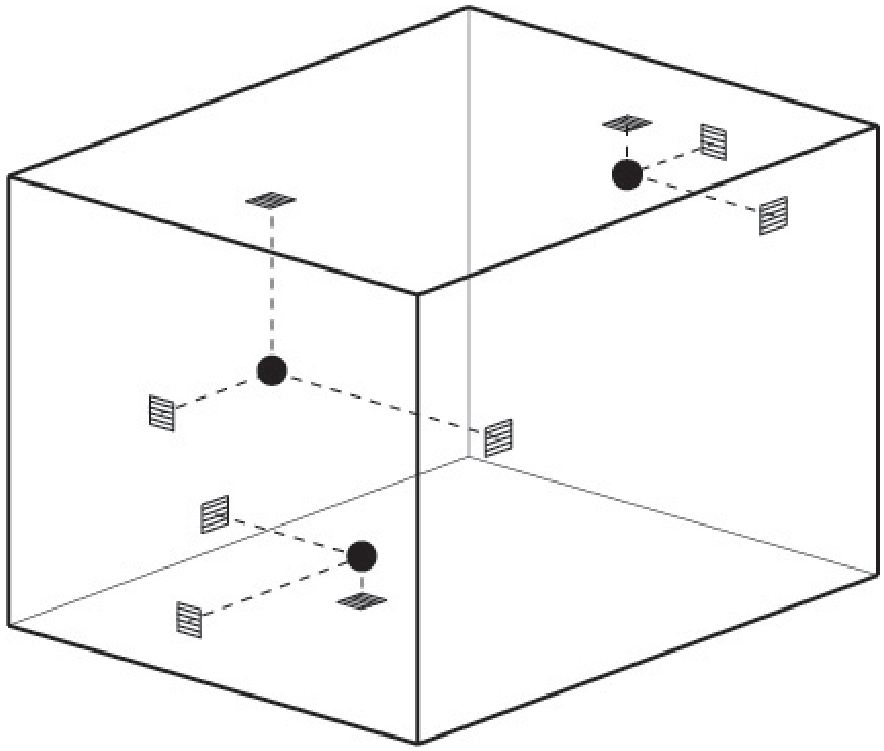
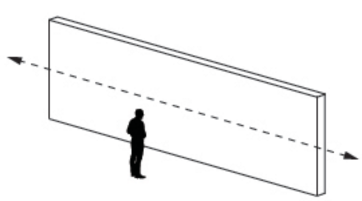


Fig 1.1 Our perception of space relies upon understanding the surrounding objects

Following Arnheim's argument as space perception occurring only in the presence of perceivable things, let us consider the case of a small, square room (Fig 1.1). The room is perceived and understood by the surrounding floor, ceiling, and wall surfaces, as well as by the objects within it. The surfaces are the dominant reference points for perceiving the floating objects within the space. Likewise, if one were to be an object within that space, one's perception will be strongly influenced by the surrounding surfaces. Arnheim adds that the physical layout of a situation can mold behavior. Distance between, size of, and material of the surface becomes important not only for identifying ones' position in space, but can also affect concerns like access, function, emotion, and even social patterns.[5] One can make instant visual judgments based on the physical layout of these surrounding surfaces. When one realizes that surrounding surfaces have spatial implications that influence perception, one understands the importance to carefully consider the design of surface.

However, not all surfaces are perceived in the same manner. While the design of all surfaces should be considered carefully, it is noted that wall surfaces are often the most readily perceived because of its verticality. Arnheim notes that the vertical acts as the axis and frame of reference for all other directions.[6] This theory suggests that the vertical surfaces in a space, typically wall surfaces, are instantaneously important for one to establish their spatial orientation. As our positioning is naturally upright, our focus in a space is typically drawn to the vertical wall surfaces first. These wall surfaces assist in delimiting the extents of the space by interrupting the horizontal planes, and establishing the reference points required for spatial perception.

The inherent formal language of these wall surfaces can go further to influence spatial perception. Architectural writer Thomas Thiis-Evensen closely investigated the spatial experience of different wall surfaces and categorized seven main spatial forms: Horizontal, Vertical, Flat (or Straight), Concave, Convex, Leaning Toward, and Leaning Away. Thiis-Evensen classified each form as having specific spatial perceptions:



Horizontal (Fig 1.2)

expresses its weight against the ground; closed and delimiting character; impulse to follow along beside it; conveys no urge to pause; an obstacle[7]

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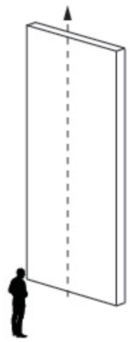
[5] *Ibid.* 268.

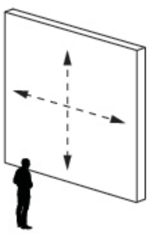
[6] *Ibid.* 32.

[7] *Thiis-Evensen.* 1989. 143.



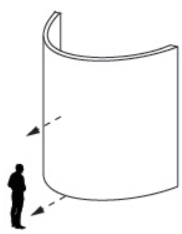
Vertical **(Fig 1.3)**

communicative; open and lighter character compared to horizontal; concentrates and attracts attention around the center area; concerns us directly as either something threatening or conversational[8]



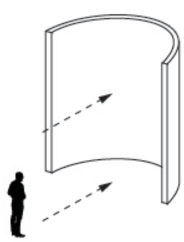
Flat, Straight (Fig 1.4)

tells us nothing about the inside-outside relationship; a stiff and impassive background like a neutral theater backdrop; expression dependent on surface treatment and openings[9]



Convex **(Fig 1.5)**

resists our approach; protecting space behind it; solid and concrete thing; outward expansion[10]



Concave **(Fig 1.6)**

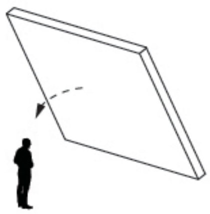
embracing and receiving; yields to our forward movement; pliant; similar feeling to nearness and protection, friendliness and security[11]

[8] *Ibid.* 145.

[9] *Ibid.* 147.

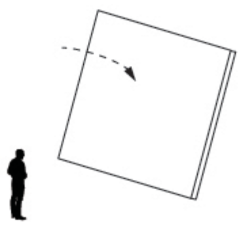
[10] *Ibid.* 147, 149.

[11] *Ibid.* 149, 151.



Leaning Toward **(Fig 1.7)**

threatening; feel safe only at a certain distance; uncomfortable and dangerous; tense excitement[12]



Leaning Away **(Fig 1.8)**

threatens space on opposite side; no longer a concern[13]

It is readily apparent that the form of the wall surface can dictate the experience of the space. Essentially, Thiis-Evensen establishes differing spatial relationships by altering the scale, depth, and angle of a typical vertical wall surface. These alterations affect the distance at which we perceive various reference points on the surface, which in turn affects how we establish our experiential condition in the space. For example, the outwardly curving wall generates a convex space that feels resistant to our approach because the central focal point of the surface is closest to our position, while the outer points are further back, which can be perceived as an outward expansion against us. Through the alteration of scale, depth, and angle, a wall surface can convey numerous expressions to the user.

Of the seven forms discussed by Thiis-Evensen, concave, convex, lean toward, and lean away represent the four most dynamic in terms of the imposed effects on our spatial experience. These spatial definitions have been heavily relied upon in our static architectural environments. In classical architecture, for example, the apse of a church (Fig. 1.9) was an inwardly-curved surface that delineated a concave spatial form, with the intention that it would orient and draw attention towards the altar with its embracing

[12] *Ibid.* 151, 152.

[13] *Ibid.* 152.

and receiving form. Even in contemporary works this application holds true, as seen in the Museum of Energy in Tarragona (Fig 1.10) where the wall surface creates a concave spatial form that draws visitors towards the entry at its midpoint. Some designers manipulate these definitions by combining forms together. The Benidorm Seafront promenade (Fig. 1.11) and Richard Serra's Band sculpture (Fig. 1.12) feature wall surfaces that combine and undulate between the four spatial forms, creating a varying spatial experience that changes as viewers move in procession around them.


Fig 1.9 Basilica of Sant Apollinare in Ravenna, Italy and **Fig 1.10** Museum of Energy by Arquitecturia

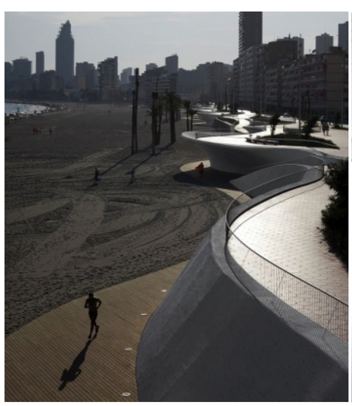



Fig 1.11 Benidorm Seafront by OAB and **Fig 1.12** "Band" sculpture by Richard Serra

While these examples and definitions reveal important concepts of spatial experience, they are founded on the static condition of surfaces. It does not explain what happens when the surrounding surfaces are not static. What happens if we take Thiis-Evensen's spatial forms and replace the static surfaces with dynamic surfaces that kinetically transform its perceived scale, depth, and angle? In what ways does this potentially affect the viewer's spatial perception and experience? Can kinetic principles effectively modify or alter the experiences of the spatial forms above? The next chapter contains a discussion on the historic and current implications of kinetics in architecture to form a basis for understanding how to answer these questions.

2 KINETICS

The following pages look at the discussions of the possibilities of architecture and environments that transform through folding, retracting, shape-shifting, and other types of kinetic movement. These discussions are necessary to understand how architecture and their spatial environments can be designed to kinetically transform, and ultimately how these environments are perceived. Though there are many different definitions and alternative terms for what I refer to as *kinetic environments*, common themes arise out of the sources explored in the existing literature. This chapter will attempt to clarify the terms commonly used in discussions, introduce the projects and technologies, and explain the potentialities and implications of kinetic environments.

Terminology

There are several terms that are intimately associated with kinetic systems in architecture. They are frequently used to characterize theories and concepts in architecture, but sometimes carry overlapping meanings. Because of their similarities, these terms are often used interchangeably in the field of architecture. This results in a convoluted dialogue between the existing literatures. A closer look at these definitions will reveal these similarities and bring clarification to the terms used for the purposes of this project.

One of the early references to a kinetic environment came from a 1970's book by William Zuk and Roger Clark. The authors introduce an architecture that is not traditionally static, but rather one that has the ability to adapt and change through kinetics. They argue heavily against the inefficiencies of immovable architecture and space solutions, citing its inability to adapt and cope with changes. Instead, they relish the idea of an architecture that is a "three-dimensional form-response to a set of pressures[14], or what they call the kinetic solution.[15] The basis of this solution is allowing a symbiotic relationship between the form and function of the spatial environment (Fig 2.1).

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[14] *Zuk*, 1970, 5.

[15] *Ibid*, 8.

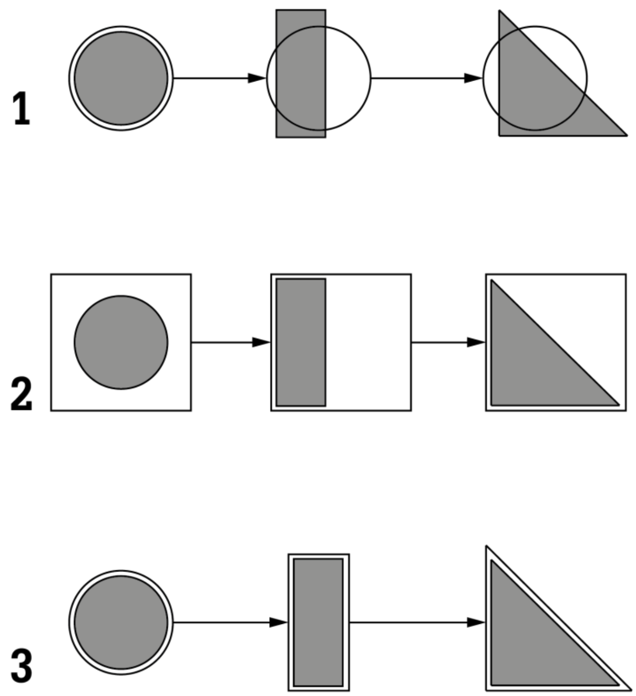

Fig 2.1 The relationship between form and changes in function. Typical static solution (number 1), universal space solution (number 2), and kinetic solution (number 3) as defined by Zuk and Clark

In 2009, nearly forty years later, a book by authors Michael Fox and Miles Kemp also visit the idea of the kinetic solution in architecture. They explain that physical adaptation in architecture necessitates kinetic movement, and is defined in the second definition listed below:

Kinetic (Zuk & Clark, 1970): adapt to continuous and accelerating change[16], a three-dimensional form-response to a set of pressures[17];

Kinetic (Fox & Kemp, 2009): transformable objects that dynamically occupy predefined physical space, or moving physical objects that can share a

[16] *Ibid*, 9.

[17] *Ibid*, 5.

common physical space to create adaptable spatial configurations[18]

It is important to note that the 1970's definition of kinetics came from a time of exploration of machines and mechanisms, while the 2009 definition arose with more advanced knowledge of intelligent, digital technology systems. However, both definitions of kinetics arise from theory and explorations that go beyond static architecture. Embedded within the above definitions of kinetic environments is the sub-concept of transformability. Robert Kronenburg, who has written much of the contemporary literature on architecture that is designed to be kinetic, has further defined this sub-concept:

Transformable: changes shape, volume, form, or appearance by the physical alteration of structure, skin or internal surface, enabling a significant alteration in the way it is used or perceived[19]

Many examples of kinetic environments have utilized the sub-concept of transformability to alter the functional usage of the space, as well as change its spatial perception. By definition, therefore, a kinetic environment, whereby the physical alteration of a structure or surface intentionally occurs, can enable a significant alteration in the way it is perceived.

The Conception

The conception of kinetic environments began with critiques of static buildings. What is often reinforced when studying architectural history and theory is the idea that a building is meant for permanence. Notable structures of the past are recognized simply for their unchanging ability to exist and remain. Materials and construction methods are tested extensively to create buildings that will stand the test of time. Authors Zuk and Clark critiqued current buildings, stating that "it has not been considered that any building might at some future time be altered, expanded, contracted, moved, or terminated."[20] It

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[18] *Fox*, 2009, 26.

[19] *Kronenbu*rg, 2007. 146.

[20] *Zuk*, 1970, 4.

is usually forgotten that users and usage constantly change, and they believed that architecture should recognize these changes.

The architectural history of primitive cultures show that their architecture was a result of shapes and forms that met their changing physical, spiritual, and social needs. Indigenous societies created buildings that reflect the flexibility of their culture. Zuk poses this example: "The compounds of northern Ghana cannot be judged by durability or permanence. Their function is to accommodate the changes that take place within the family unit."[21] Depending on the needs of the family, a structure would be added to, separated, or deleted. The adaptive handling of this type of continual flux was an important characteristic of primitive architecture, one that understood how to adapt alongside its changing social condition.

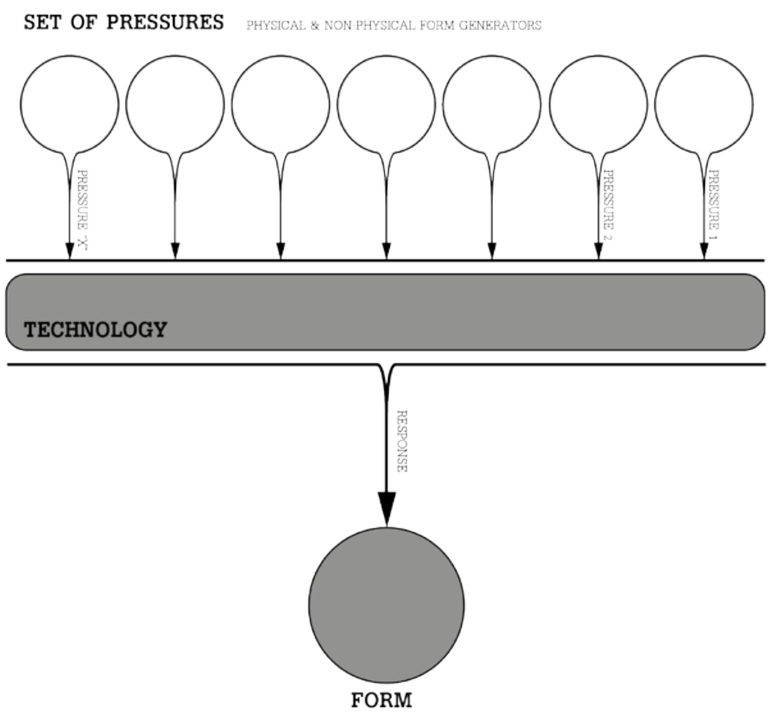

Fig 2.2 Pressure-Response Diagram showing the relationship between pressures, technology, and form

[21] *Ibid*, 4.

Although the principles learned from primitive societies can be studied thoroughly, it is not entirely applicable to our current world. Our complex and rapidly changing society has a radically different set of principles and extensive layers of changing needs. Zuk and Clark suggest that the approach to an appropriate architecture for this society is one whose form responds to the changing pressures. This pressure-response relationship is what the authors argue is the reason for a kinetic architecture (see Fig 2.2).

It is also important to note that as living beings, constant changes to our outdoor climate are definitive influences on our species. Fluctuations in daylight and weather patterns are powerful means of dictating our human actions. It is within our nature to be accustomed to these environmental changes, as well as the subsequent changes it requires of ourselves. Kronenburg believes that "a part of our success as the human race is our inbuilt need for change and improvement."[22] Kinetic environments acknowledge an aesthetic that simply matches our adaptive and progressive nature.

American writer Stewart Brand critiques the lack of consideration for the adaptive-ness of buildings. He notes that "all buildings are forced to adapt over time because of occupation and deterioration, yet very few buildings adapt gracefully."[23] Brand poses that space should be designed in order to handle the inevitable changes of the future. Like a window that needs to be open or closed for comfort, walls and floors often need to change in order to satisfy some aspect of human occupation. He believes that architects should be providing spaces that can recognize and be adaptable to these changes of human occupation. Kinetic principles applied to the architectural environment can provide these adaptable solutions. What this means is that the mechanics of the architecture become relevant to the user of the space, and the "adapted state is not the end state."[24]

The longstanding practice of architecture was to develop form that responds to singular issues that are seen. In the age of modern architecture of the 20th century, the idea of universal space pervaded the design community. Architects willingly embraced blank, minimalist spaces. The issue of how to deal

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[22] *Kronenburg*, 2007. 14.

[23] *Brand,* 1994. 2.

[24] *Ibid,* 209.

with multiple functions was answered with a large, generic space that is not suited to any particular function. This solution unintelligently overestimates the space required, and "while attempting to solve all functions, actually satisfies none."[25] Many would pose the argument that a single static form usually does not effectively handle issues that change over time and what is needed is a dynamic response, a kinetic answer that can transform the environment as the pressures dictate.

Though Zuk and Clark's book on kinetic architecture is dated, it was one of the first texts to delve into this kinetic design paradigm. At around the same time, groups like Archigram and architects like Nicholas Negroponte have made contributions to the field and their explorations have led the discussions. The many explorations covered in their work prove the breadth and depth of the study of kinetic transformability in architecture: from kinetically controlled static structures, to architectural machines, to mobile, deployable, and disposable architecture. With substantial technological developments constantly advancing the field, the spectrum of kinetic architecture and its possibilities has been clearly evolving and expanding from these early ideas.

The Evolution

Research and development of technologies have assisted the evolution and expansion of kinetic environments. The possibilities evolved from purely mechanized structures into responsive and adaptive systems, large scale building transformations, deployable structures, and intimate interactive facades. It is important to note how the development of technologies has impacted these projects, in order to comprehend the current understanding of the paradigm as well as the implications for future kinetic design strategies.

What is clearly noticeable in the design of early kinetic environments of the mid twentieth-century are the thoughts toward mobility, expansion, and contraction from a purely functional standpoint. Many of their explorations feature transformability from a small, portable configuration, into a larger expansive space for function. The design of the spatial envelope was important; the configuration and materiality of the

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[25] *Zuk*, 1970, 9.

envelope had to be considered for both the contracted and expanded form. These early projects reveal the concept of folding as essential to expansion and contraction. Zuk and Clark define two types of folding: one that can fold as a result of hardware, the other as a material with inherent properties that allow it to fold.[26]

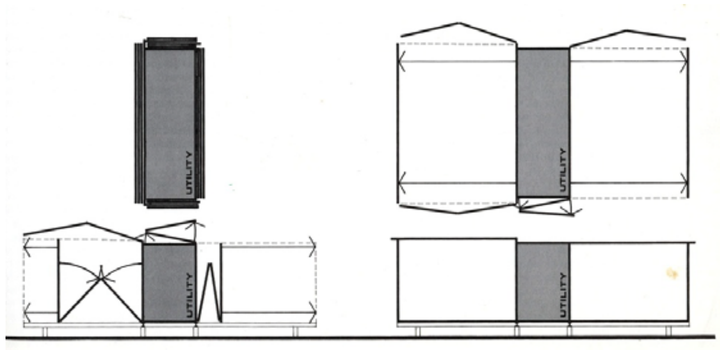


Fig 2.3 Expendable House by Carl Koch (1948). The 810 square feet house transforms into a 160 square feet movable unit.

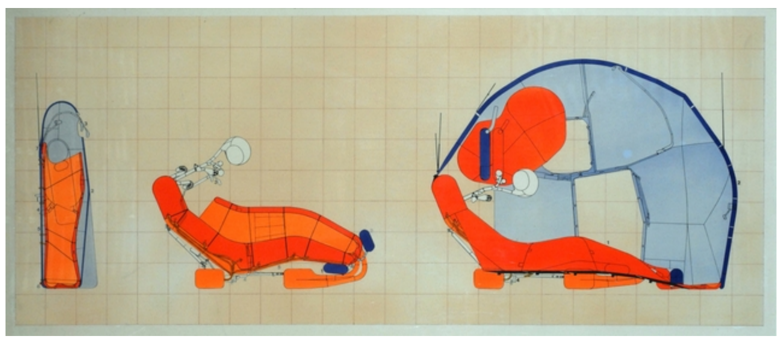


Fig 2.4 Cushicle/Suitaloon by Archigram (1966). airCUSHion vehICLE was a portable sack that would unfold to provide many amenities of the contemporary living room.

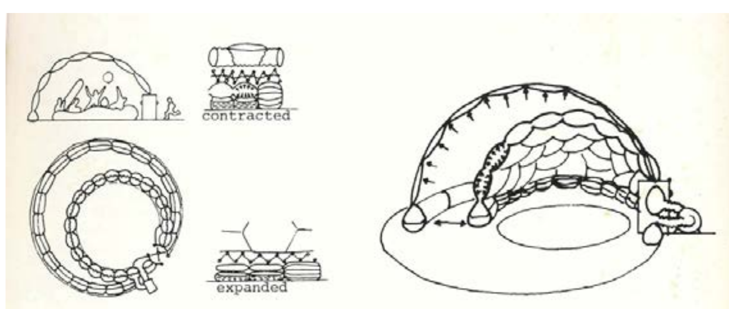


Fig 2.5 Designed by ERG, Diagram by Sean Wellesley-Miller (1968). Air pumps control the contraction of the play space.

[26] *Zuk*, 1970, 99.

The Expendable House (Fig 1.3) folds linear surface partitions via the connecting hardware, expanding the amount of perceivable space. The rigid planar surfaces were not transformable within itself, but instead relied on strategic subdivisions, with hinges for expansion and contraction of the space. On the other hand, the Cushicle (Fig 1.4) and the ERG Play Space (Fig 1.5) utilize surface materials that have the inherent capacity to fold. These kinetic environments relied on the fabric-like nature of the material surface to fold into each other, allowing the space to contract for mobility or expand for enclosure.

These systems were not without fault. The two types of folding may experience problems if the systems, cabling, and other parts run through these folding parts. The folding materials/surfaces must be designed as not to damage these parts through the process of folding and all of its extensions. Nevertheless, these explorations by these early pioneers have revealed the practice of surface folding as a vital characteristic of kinetic environments.

Closely following the explorations of surface folding in kinetic environments was the concept of structural folding. Chuck Hoberman, an inventor of transformable structures, has explored objects that are half-structure, half-mechanism[27], and is well known for his Expanding Geodesic Dome and the Mechanical Curtain for the 2002 Winter Olympic Games in Salt Lake City. Like the earlier examples, Hoberman's objects also expand and contract, but do so by way of the structural framework (see Fig. 1.6). His years of exploration and experiments have founded his basic criteria for the process of transforming objects, a process that is: complete and fully three-dimensional, smooth and continuous, reversible and repeatable.[28] He defines the transformation of objects as a "conceptual framework that draws on mathematics, mechanics and structural engineering. It is an approach that is inspired by nature, not from a visual standpoint, but rather from a functional one."[29] Others likewise share Hoberman's sentiments; using different terminology, Michael Fox defines spatial optimization as a "kinetic environment that can, from a practical standpoint,

[27] *Kronenbu*rg, 2006. 71.

[28] *Ibid,* 70.

[29] *Ibid*, 70.

serve as a means for adjusting spatial configurations based on changing stimuli triggered by environmental and/or human actions."[30]

Fig 2.6 Expanding Geodesic Dome by Chuck Hoberman (1991). Deployable by pulling outwards at the base

Fig 2.7 Animaris Rhinoceros and **Fig 2.8** Animaris Umerus.

Fig 2.9 Jansen Mechanism.

The work of the Dutch artist Theo Jansen also embodies kinetic structural principles based on changing environmental stimuli, but for thoughtful sculptural purposes rather than spatial function. Jansen

[30] *Fox*, 2009, 31.

creates kinetic sculptures, called *Strandbeesten,* or "Beach Animals" (Fig 2.7 and 2.8), that are influenced by the surrounding wind conditions and react through "walking" movements. They become an event in themselves, capturing the viewer's attention with a unique, dynamic connection that static sculpture would have difficulty in achieving. These kinetic sculptures do not necessarily constitute an architectural space that is inhabitable, but the kinetic principles learned from them have application in the design of kinetic environments.

Jansen created a mechanism that responds to a single rotating shaft, allowing the sculpture to "walk". This geometry is made up entirely of straight and linear components, connected by hinge points. Jansen's sculptures are often skeletal as a result of this geometry, but they can be replaced with surfaces (as in Figure 2.7). The only movement, therefore, is the movement of the geometry and not a material property change of the surface or structure. In such a system, the design of the geometry is not only a functional consideration, but one that also determines the extent to which the movement is perceivable to the viewer.

From these highly mechanized kinetic systems of the past and present, there has been a quick evolution towards robotic automation. The incorporation of sensors, actuators, and computational systems are becoming more prevalent in kinetic environments, as the technology becomes easier and cheaper to access. This shift also comes from the human life patterns of the twenty-first century. Fox and Kemp talk about lifestyle changes and how there is a demand for increased flexibility at home and in the workplace.[31] They believe it is important for architects and the architecture itself to be cognizant about these changes in lifestyles. Embedded computation within kinetic systems can provide intelligent and automated solutions to these lifestyle changes, and architects and designers are experimenting with the technology in the creation of kinetic environments that are interactive and responsive to the demands of everyday life (Fig 2.10).

[31] *Fox*, 2009, 140.

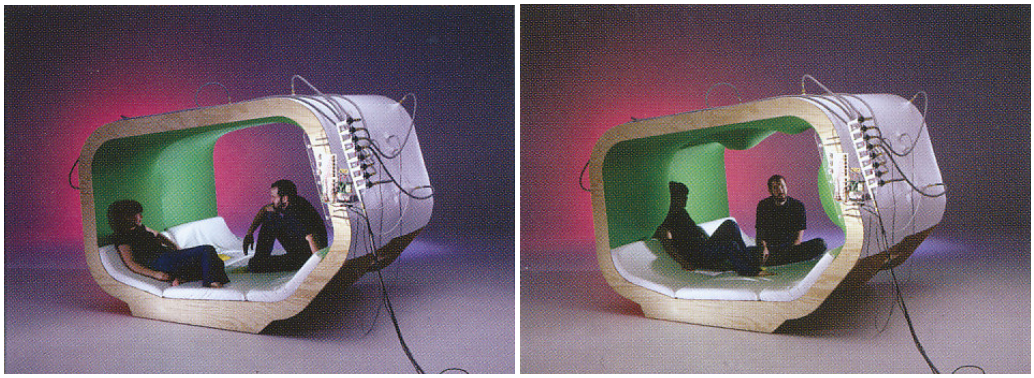


Fig 2.10 Interactive Design Studio by Michael Fox (2009). A living environment with "embedded computation"

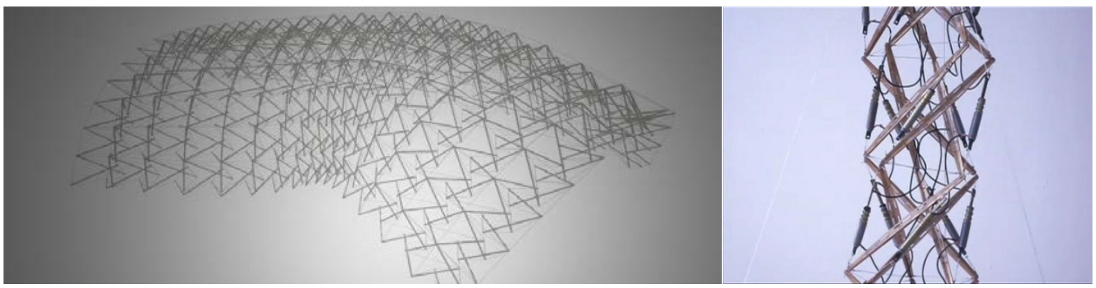


Fig 2.11 Actuated Tensegrity Structures by ORAMBRA (2001). 3-D interactive and responsive wall surface

Fig 2.12 Hylozoic Ground. Immersive, interactive sculpture environment

The evolution of embedded computation in kinetic environments has continued through the recent work of architect Tristan d'Estree Sterk and the Office for Robotic Architectural Media & Bureau for

Responsive Architecture (ORAMBRA), as they continually examine the possibilities of architecture aware of its surroundings. Using the term “functional responsive architecture”, Sterk proposes that “the ideal version is one that can provide shelter against changing conditions, as well as calculate how these changes affect the type of shelter needed.”[32] Sterk’s explorations, which he calls “actuated tensegrity structures”, rely on sensory inputs and mathematical measurements to direct the actuators that transform the environment.

A step beyond these explorations is Hylozoic Ground. Hylozoic Ground, developed by Philip Beesley, is a fully-immersive and interactive environment with responsive, kinetic sculptures. The environment is designed and organized to support responsive actions, dynamic material exchanges, and “living” technologies. Beesley describes it “as a suspended geotextile, gradually accumulating hybrid soil from ingredients drawn from its surroundings.”[33] What Beesley has created is a highly organic solution to a kinetic environment that doesn’t appear mechanical, but biological. Utilizing robotics, valves, electronics, sensors and *Arduino* microcontroller boards, Beesley was able to create a bio-morphic structure/system that feeds off the interactivity of the users surrounding it. Beesley mentions that Hylozoic Ground is “akin to the functions of a living system”[34], as “the microcontrollers feed off sensors that cause the actuators fitted inside his network of columns to produce contracting and expanding movements”[35] Beesley describes this system as a space-reading sonar similar to those in dolphins and bats, working to guide movement of the environment. In addition to Beesley’s mechanized components, he introduces a “wet system” that contains flasks of liquid-supported artificial cells that are monitored and govern the behavior of the system.[36] Beesley’s exploration convincingly conveys the possibilities of an organic atmosphere that recognizes human occupation. Hylozoic Ground relies on simple mechanisms, but incorporates systems of embedded computation in such a way that the environment seems to undergo complex transformations and organic movements.

[32] *Sterk*, 2003, 88.

[33] *Beesley,* 2010. 14.

[34] *Ibid*, 14.

[35] *Ibid*, 18.

[36] *Ibid*, 20.

These projects are representative of the evolution of the kinetic environment design paradigm. They cover a wide range of projects that are responsive solutions to social, psychological, and environmental implications of the human condition, from the simple mechanical solutions of the 60's to the contemporary reliance on sensory-actuated systems. In the case of highly mechanized projects, kinetic systems carry practical issues. "Problems occur in three main areas: movement mechanisms, joining of internal and external partitions, and operation of services under the different conditions. The mechanisms employed to enable movement to take place should be robust, maintenance free, easily operable and reliable."[37] Opposed to static building, the risk for failure increases with the amount of moving parts utilized. Ensuring proper operation means a likely increase in maintenance costs. It will be left to future technological advances to generate ideas and experiments that produce effective, more robust kinetic systems that minimize these disadvantages. As with any new approach to an existing body of knowledge, it is likely to create conflict. "The point to be made is that the evolution of a new idea or concept potentially carries with it many far-reaching implications or consequences."[38] Despite this, it is clear through these projects that over the years, the advent of new technologies has certainly minimized these problems and is continually pushing the innovation of kinetic transformability in surfaces and structures.

The Perception

Though the advancements in kinetic environments continue to expand and evolve, the potential effectual impacts it has on spatial perception and experience has been barely realized. The ability of kinetic environments to create complex spatial experiences has been infrequently attempted in architecture, primarily because kinetic environments were first conceived from a purely functional standpoint, rather than for the purpose of experiential quality. Utilizing kinetics to create environments with dynamic, expressive spatial definitions also requires a different set of spatial principles from the static definitions explored in Chapter 1.

Consider Theo Jansen's kinetic sculptures again. Most static sculptures are objects that do not surround the viewer, but still occupies the space one is in, generating a static spatial relationship. With

[37] *Kronenburg,* 2007. 146.

[38] *Zuk*, 1970, 144.

kinetic sculptures like Strandbeesten, however, one's perception of space is continually modified as the sculpture's movement changes the occupancy of the space over time. For example, if one were to imagine the space between oneself and one of Jansen's sculptures, one would have to consider several factors and questions: *Is the sculpture walking away from me? If it walks towards me, do I have to step out of the way? How much space between us is necessary before I feel the need to move out of its walking path? Does my safety feel threatened by the movement?* Although these questions appear to be inane, they speak to the psychology of spatial experience when kinetic movement is involved; when the occupancy of space changes as a result of kinetic movement (most often when there is an intrusion into personal space) the perception of that space is modified.

This thought process is important to consider when designing kinetic environments, as one's spatial perception continually shifts as movement occurs. Understandably, these ideas were missing from Arnheim's analysis of architectural form because the architecture of his time remained largely immobile. Interestingly though, Arnheim did acknowledge the importance of movement in another book discussing the visual perception of art, where he stated that motion is the strongest visual appeal to attention as "motion implies a change in the conditions of the environment, and change may require reaction. It may mean the approach of danger, the appearance of a friend or of desirable prey."[39] Therefore kinetic environments, where motion is highly prominent, inherently command our attention. Our spatial experience of these kinetic environments, though still relying on the surrounding perceivable surfaces, also depends largely on our assessment of the type of movement involved.

Kinetic environments recognize the dynamic nature of our world by interacting and adapting to the changes we require through movement. In addition, kinetic systems also build a reciprocal and symbiotic relationship between the spatial environment and user, which is opportunity for generating interesting spatial experiences. The movement of surfaces adds another layer to our spatial perception, whose importance is akin to surface geometry and materiality, and ultimately has the potential to supersede existing definitions of spatial experience. As such, applying kinetic principles can work in accord or

[39] *Arnheim.* 1974. 372.

against the geometry and materiality of a surface, creating extremely expressive or even contradictory spatial experiences, depending on the strategy employed. The case studies in the next chapter provide precedence by showing how kinetic transformability can create captivating spatial experiences through the modification of surfaces, as well as support the beginnings of creating a refined framework for understanding the spatial perception and experience of kinetic environments.

3 CASE STUDIES

BENGT SJOSTROM STARLIGHT THEATER

Architects: Studio Gang Architects

Location: Rockford, IL, USA

Year: 2003

Fig 3.1 and 3.2 Exterior and interior shots of the Starlight Theater.

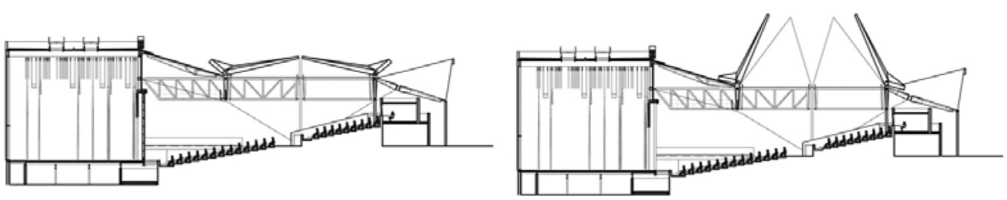


Fig 3.3 roof transformation.

The Starlight Theater was designed to replace an existing outdoor venue with expanded facilities for the performing arts. The design incorporates a large transformable roof design that can open and close. Although the six-panel roof is not the main focal point of the performances that take place at the theater, it creates an added dimension of spatial experience. It becomes a kinetic blurring on the porosity between inside and outside spaces and showcases the potentiality of architectural surface transformation.

According to Arnheim, the worlds of outside and inside are mutually exclusive; one cannot be in both at the same time perceptually and practically.[40] Arnheim goes on to state, "when an oculus in the roof reveals a bit of sky, we do not really acknowledge another space but perceive it as a recessed portion of the room's boundary."[41] However, what happens to this perception when the scale of the oculus is not only much larger in scale, but also transformable by design?

Fig 3.4 roof aperture

The Starlight Theater sits on the border of this theory of spatial perception. Each cantilevered triangular-roof-panel is 42 feet long, which creates a significantly large aperture to the sky when moved to the fully open position. Rather than a recessed portion of the room's boundary, it is arguable that an aperture of this size and scale could be perceived as an extension of space. Viewers may still perceive themselves to be indoors, but there is likely to be a point during the transformation of the roof from closed

[40] *Arnheim*. 1977. 92.

[41] *Ibid.* 93.

to open where the boundary becomes less intrusive. Though some may not feel like they are in an outdoor space, their spatial perception relies greatly on the roof-panel edges, which act as the visual reference point between indoors and outdoors. This perception would also change depending on the distance between the viewer and the aperture. Compared to a viewer at ground level, the viewers seated higher and closer to the roof opening may perceive more of the outside space and "leave" the indoor space visually, although they would never pass the threshold of the aperture. This is assuming, of course, that the roof surface has transformed wide enough to allow for such a perception.

It is also important to note that the roof transformation occurs in the direction opposite of the viewer. The surfaces would be perceived to "lean away" from the viewer, becoming less of a psychological concern according to Thiis-Evensen. The Starlight Theater, then, is a demonstrative example of a transformable surface where the edges, size, and scale of the aperture are the main factors of changing spatial perception.

AEGIS HypoSurface

Architects: deCOi

Location: Birmingham Hippodrome Theatre; Worldwide Installation

Year: 1999

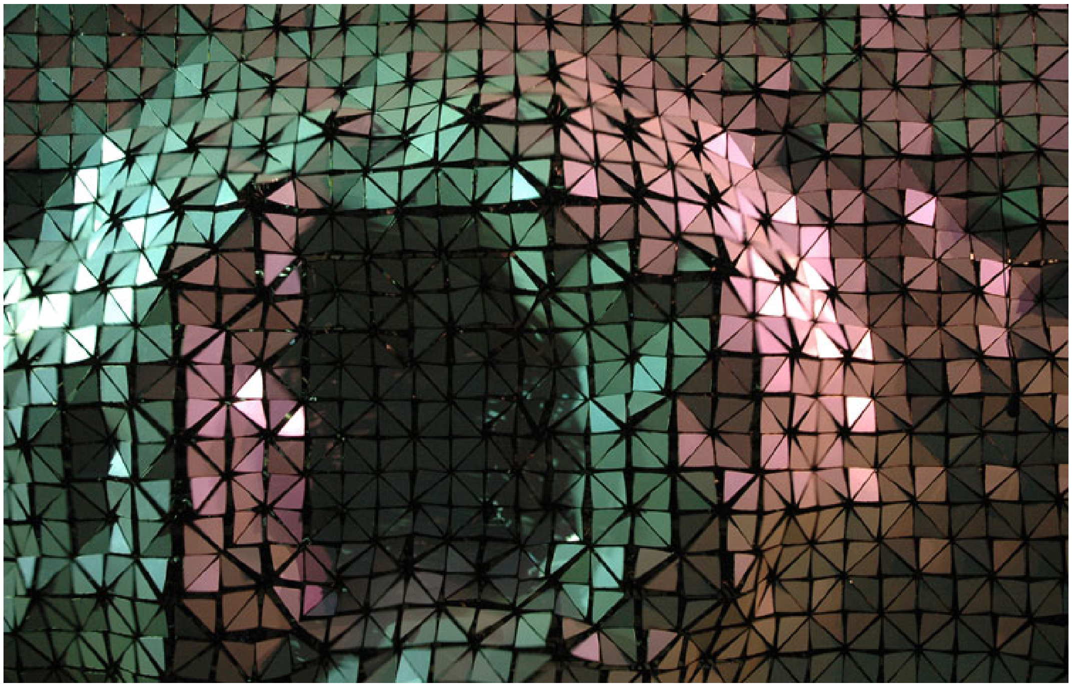


Fig 3.5 AEGIS Hypo-Surface by dECOi (1999). Interactive and responsive wall surface

The AEGIS Hypo-Surface project was initially conceived by Mark Goulthorpe and the dECOi office as an interactive installation for the Birmingham Hippodrome Theatre. The installation, completed by a team of architects, engineers, mathematicians and computer programmers, is a vertical wall composed of faceted metallic surfaces that move fluidly in and out of plane, creating a fascinating visual array of undulations. Behind the wall, 896 pneumatic pistons are set up in a matrix system that drives the movement of the surface in real-time response to various electronic stimuli. By way of different environmental sensors, the system recognizes movement, light, and sound in the surrounding environment, and responds with a derived movement. The surface has proved to provide a captivating experience for viewers, and many find themselves attracted to the kinetic nature of the system.

I posit the reasoning behind AEGIS Hyposurface's success is due largely in part to the rapid motion and perceived elasticity of the surface. The highly complex network of sensors and pneumatic actuators in AEGIS Hyposurface are capable of handling large displacements at a high rate of speed, which helps users easily identify that their actions indeed affect the movement of the surface and thus encourage interaction. Other kinetic systems that were built to be responsive and interactive are often limited by the speed at which the actuators, motors, or other moving parts operate, which is a detrimental factor in the user determining their relationship to the surface. In the case of a truly interactive kinetic environment, if the system cannot keep up with the user's motion input, the experience can become less interactive and dissatisfying. This technological limitation was overcome in dECOi's installation and the result is a highly engaging kinetic surface.

Fig 3.6 Interaction with the kinetic wall surface

If we take the static condition of AEGIS Hyposurface, it would likely fall under Thiis-Evensen's Horizontal spatial category, as it is a flat wall that is long in the horizontal dimension when it is not moving. By his definition, this space should have a basically closed and delimiting character and is an obstacle that draws the viewer to either side, as if seeking an entrance around the corner[42]. Though possibly true in Hyposurface's static state, this is clearly not the case when the wall begins to move. The space retains its "horizontality", but the motive wall surface becomes an event unto itself, and is perceived as inviting and engaging rather than closed and delimiting, as seen in Fig 3.6. It could be argued that this is because Hyposurface creates geometries that Thiis-Evensen defined as inviting, such as the concave volume seen in Fig 3.5, but the surface is moving too fast to experience the form of that volume in its entirety. The real attraction that initially draws the user towards the surface must be the frequency and fluidity of the motion, while the interactive capabilities of the surface acquires and retains their attention.

[42] *Thiis-Evensen.* 1989. 143.

It's important to note here that the surface itself is not a solid, continual surface, but composed of hundreds of fragmented subdivisions. These subdivisions are essentially planar triangles with sharp edges, but it does not deter people from engaging with the surface. This is because the movement of these subdivisions is in accord with the overall movement of the whole, so one perceives the surface movement in its entirety, rather than being overwhelmed with sporadic and unrelated motion across the surface. This is important because we learned from Arnheim that space perception occurs when we perceive surrounding objects, namely the surface subdivisions in this case. If the kinetic motion of these subdivisions acts in a way where one perceives many separate and complex types of movement at the same time instead of simple fluid gestures, it would be initially difficult and overwhelming for one to keep up with the changes. Hyposurface's fluid and wave-like motions supersede the harshness of the subdivisions' fragmented geometry, making it more approachable.

There is also the factor of "unpredictability" to consider. Upon observing the users interacting with Hyposurface, it is interesting to note that though many are initially drawn to the surface, they do not seem entirely sure of the kinetic movement. Apart from the designers and programmers of Hyposurface that know the extents and logic behind the movement of the surface, most who approach the surface for the first time are likely unsure of what it is capable of. Yet, they engage in a level of risk (albeit minute) to touch and place their body onto Hyposurface. In some sense, I think this can be likened to how humans react to animals; One may not understand what the animal is thinking, but the unpredictability of the animals thoughts and actions, in addition to the inherent kinetic nature of the animal, actively engages one's interest and curiosity. Static wall surfaces aren't perceived to have "thoughts" of their own, but kinetic wall surfaces like Hyposurface appear to act unpredictably on their own, and the spatial experience can be much more engaging.

AEGIS Hyposurface generates part of an environment that is reciprocal and fluid in its interaction with users, and it's a successful example of how the movement of surface becomes convincingly attractive. On the other hand, the dECOi team could have also modified the kinetic design principles of Hyposurface to use movement to create the opposite effect of repulsion, or even use it to dictate the movement of users within the environment. The possibilities are endless so long as one has a good understanding of how to modify the kinetic variables of the system to generate those specified spatial experiences.

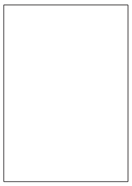
As we've seen in both case studies, the method of how a surface moves and transforms is vital to the range of perceptions and spatial experiences it conveys. The next chapter contains explorations of different kinetic surface transformations and their proposed effects on spatial experience.

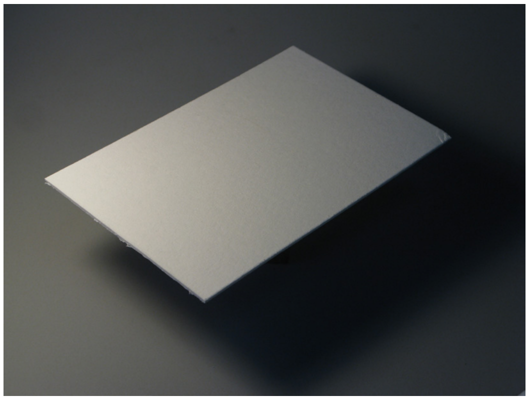
4 **SURFACE MODEL CATALOG**

As stated in the literature research, *transformable* is that which "changes shape, volume, form, or appearance by the physical alteration of surface, enabling a significant alteration in the way it is used or perceived." This series of models contains explorations and analysis of simple kinetic transformations applied to a surface in order to document the perceivable changes.

EXPLORATION MATRIX

00



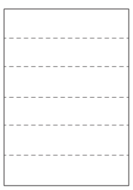


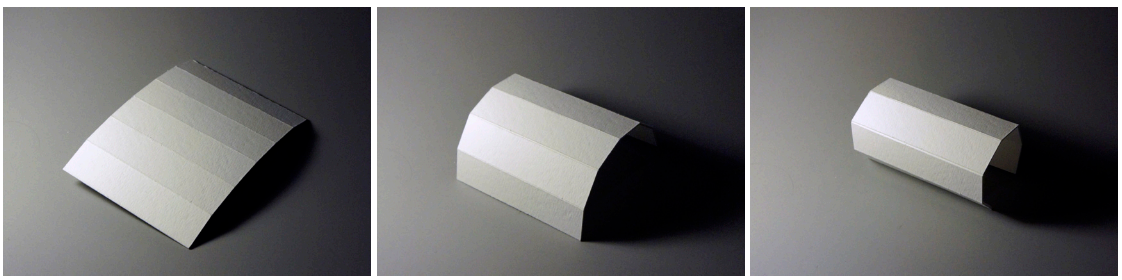
static 4 x 6 surface

This surface is defined only by the texture of the material and its surrounding four edges. Through the physical alteration (transformation) of this standardized surface, the perception of the surface and the space around it can be altered. The models on the following pages explore these ideas.

Exploration Set A: linear fold

a1

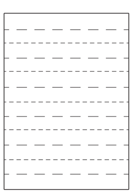


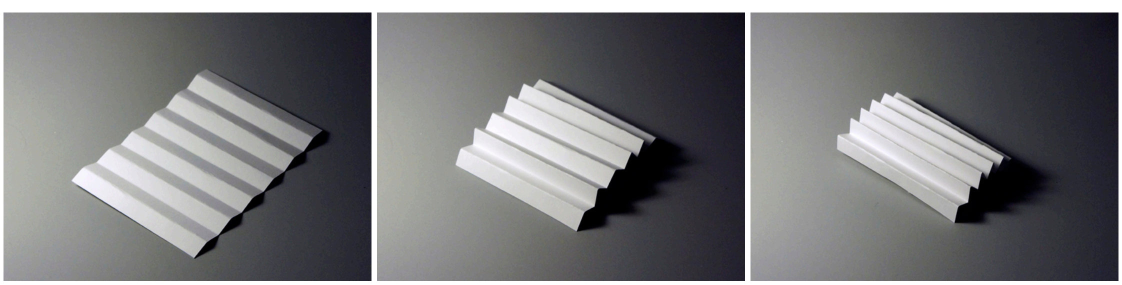


One of the simplest transformation methods for a surface is folding. By folding the surface outside of it's two-dimensional plane, the volume of perceivable space becomes altered. In this example the curvature is in the convex direction towards the viewer, subtracting volume from one side of space, and creating and partially enclosed volume on the other when it folds.

Tags: *fold, depth, enclose, convex*

a2



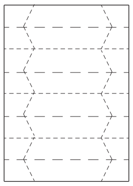


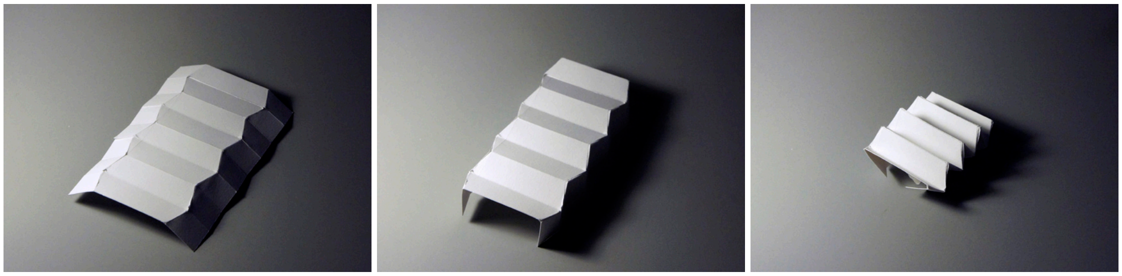
By simply alternating the folds of **a1** on both sides, the surface enables itself to expand and contract. This property can affect spatial perception in many ways: by revealing space, obstructing view, collapsing itself to become less visible, or by the dimensions of the fold giving the surface a perceivable thickness.

Tags: *fold, scale, expand, contract, collapse*

Exploration Set A: linear fold

a3

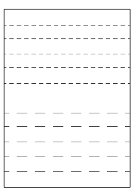


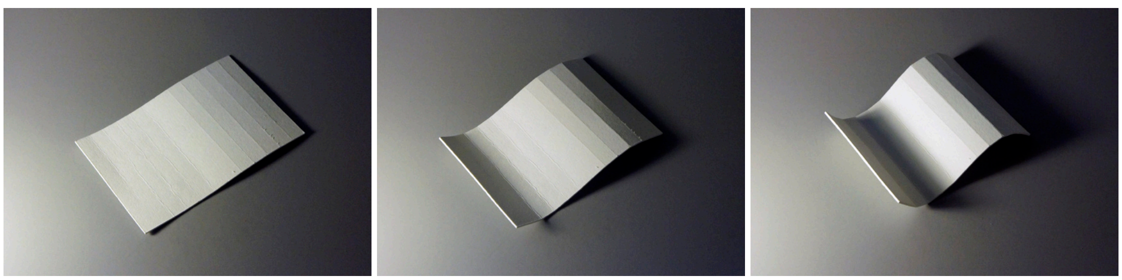


Similar to **a2** and borrowing from techniques of origami, this surface transformation allows it to expand and contract, and collapse into an even smaller form. This technique generates a transformable surface that significantly changes in scale from the initial form.

Tags: *fold, scale, expand, contract, collapse*

a4

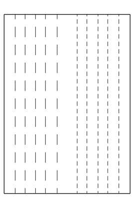




Reversing the folds of **a1** midway through the surface allows a surface form that is both convex and concave. Based on Thiis-Evensen, this would feel both resistive and embracing, a contradictory effect. The form is thus very suggestive, and could be convincing in ushering one's experience.

Tags: *fold, depth, convex, concave*

a5

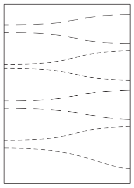


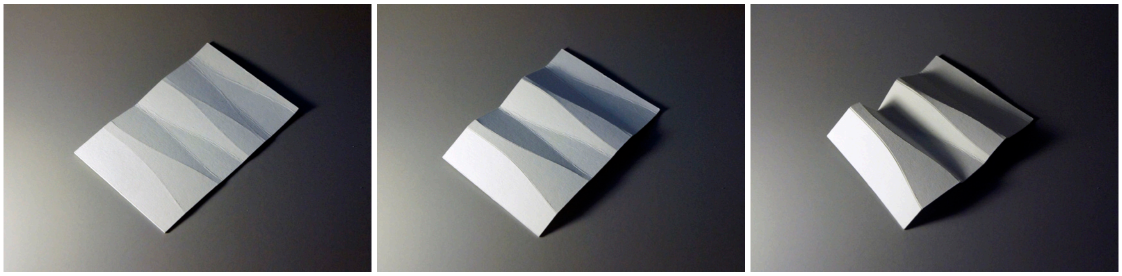
Similar to a4 except that the fold runs longitudinally across the surface, which results in a minimal change to the surface. As a result, this transformation is limiting in its ability to alter the perceived surface depth.

Tags: *fold, depth, convex, concave*

Exploration Set A: linear fold

a6





Experimenting with an alternating curvilinear pleat, this surface clearly articulates its depth and creates a greater sense of pocket-like enclosures. This is due to the perceivable planes of the surface shifting by way of its transformation.

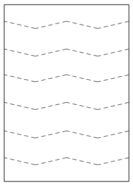
Tags: *fold, depth, enclosure*

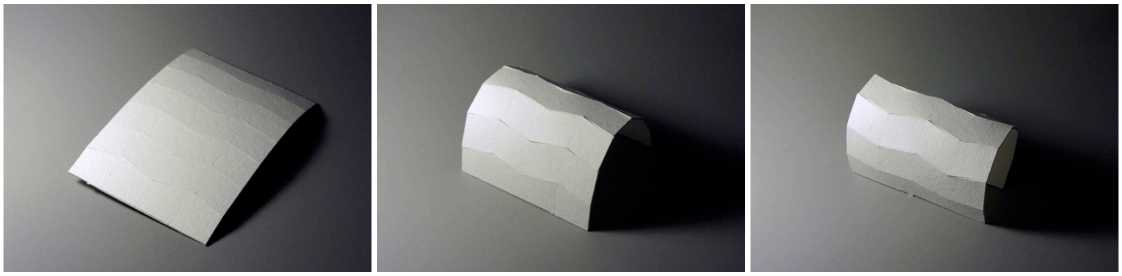
Exploration Set A Summary

This set of linear fold explorations best highlights the alterations of *scale* and *depth* through the expansion and contraction of surface. By simply allowing the surface to fold in-and-out of plane, the perception of surface goes from flat to revealing or creating new volumes. As seen in the literature research, these concepts were especially relevant to the design of kinetic environments that demanded mobility and portability. Further exploration and analysis of these transformations could be done to determine the most compact and efficient folding techniques for portability. However, rather than focus on functional considerations, this research is most concerned with transformations for the purposes of manipulating the experience of space. Exploration **a4** (which transforms itself as a contradictory convex and concave form) could be further utilized in generating a spatial environment that could usher a user within or through a space in multiple directions by continually adjusting the suggestive nature of the form.

Exploration Set B: zigzag fold

b1

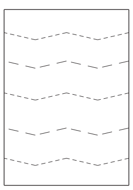


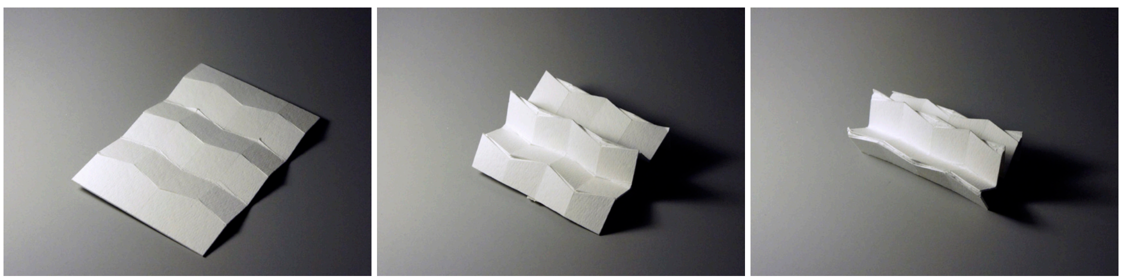


These explorations borrow on the ideas of the linear fold from **a1**, but with slight variation in the fold lines. As seen from these last images, the variation creates a slight, but perceivable difference. When the surface folds, the pleat pattern lines become the prominently featured edges that define the various perceivable portions of the surface.

Tags: *fold, depth, enclose, convex*

b2

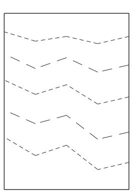


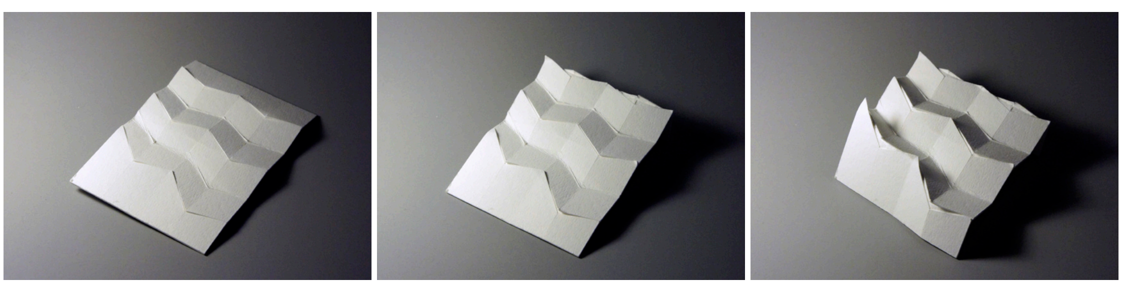


Alternating the folds of **b1** revealed the same concept of expansion and contraction of **a2**, though there is no apparent additional benefit to this transformation with regards to effects we've seen in previous instances.

Tags: *fold, scale, expand, contract, collapse*

b3



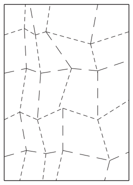
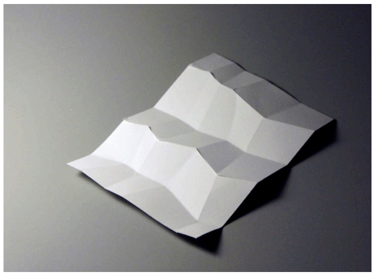
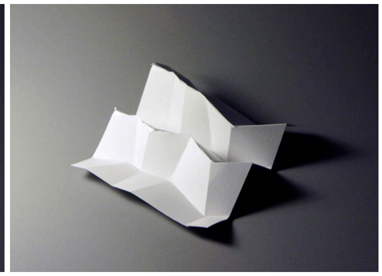
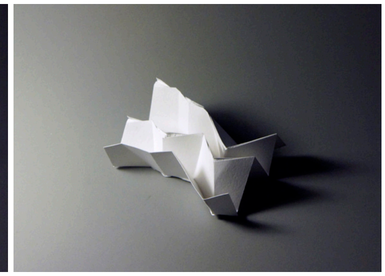


This model attempted to skew the fold lines in **b2** to generate an asymmetrical surface transformation. This skewed geometry made it more difficult to collapse the surface fully as in other models. More than anything else, the asymmetrical geometry drove attention to the variation of shadows and highlights when folded.

Tags: *fold, angle, expand, contract, shadows, highlights*

Exploration Set B: zigzag fold

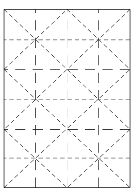
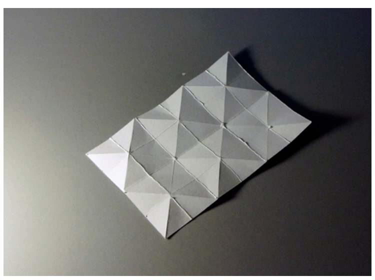
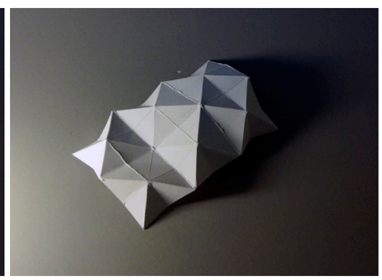
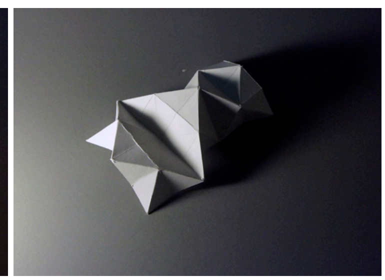
b4

Furthering the idea of asymmetrical transformation, this model was an attempt to create an asymmetrically collapsing surface. Using alternating zigzag pleat lines, this surface was able to expand, contract, and collapse itself like earlier models, but with varying dimensions of the fold. As this surface transforms, the sharp, varied edges of the fold are perceived as foreboding, while the expanding/contracting nature implies additionally pleasing/disconcerting notions.

Tags: *fold, scale, expand, contract, collapse*

b5

Diagonally bisecting surface **a2**, this model was an attempt to create a zig-zag transformation throughout the surface. The results are similar to the above models, with emphasis on skewing the perceivable surface angles in multiple directions, which cause dynamically changing shadows and highlights. This tesselation also eventually helped lead to the triangulated fold models in Exploration Set C.

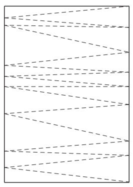
Tags: *fold, scale, expand, contract, shadows, highlights*

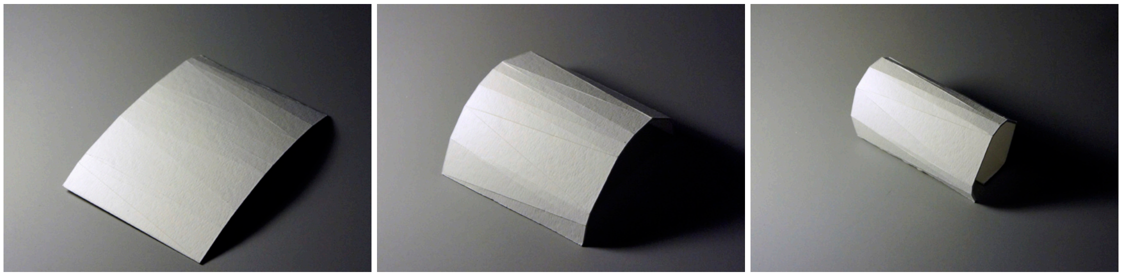
Exploration Set B Summary

Similar to the models in set A, these zigzag fold explorations exemplify the ideas of expansion and contraction of surface. The ability to expand and contract along its dimension imposes a similar feeling of expansion and contraction to the viewer. Exploration **b5**, for example, shows a surface where the contraction in one direction expands sharp edges in the perpendicular direction, which could be used to create a kinetic environment where the user experiences both the feelings of outward expansion and contraction together with the changing space. Another observation is the fluctuation of shadows and highlights as the surface transforms, which adds complexity in the ability to visually understand the surface.

Exploration Set C: triangulated fold

c1

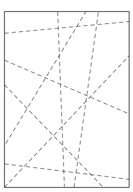


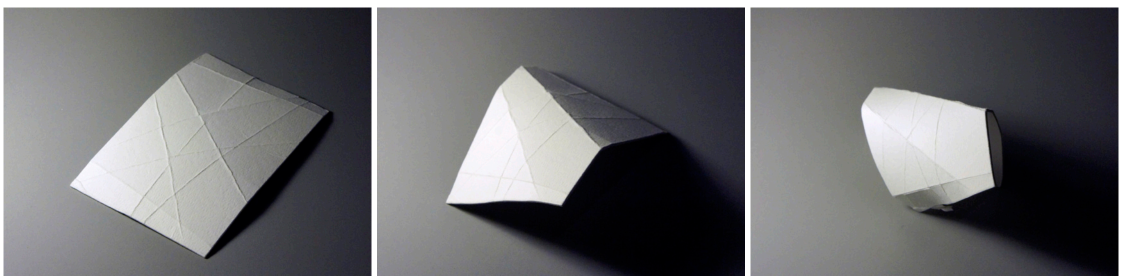


Revisiting the results of **b1**, this was an exploration into transforming a surface into an asymmetrical, partially enclosed surface. By dividing and folding the surface into random, triangulated polygons, the resulting enclosure is irregular in shape and section, but only encloses in one general direction.

Tags: *fold, depth, enclose, convex*

c2

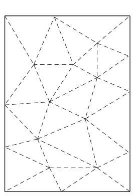


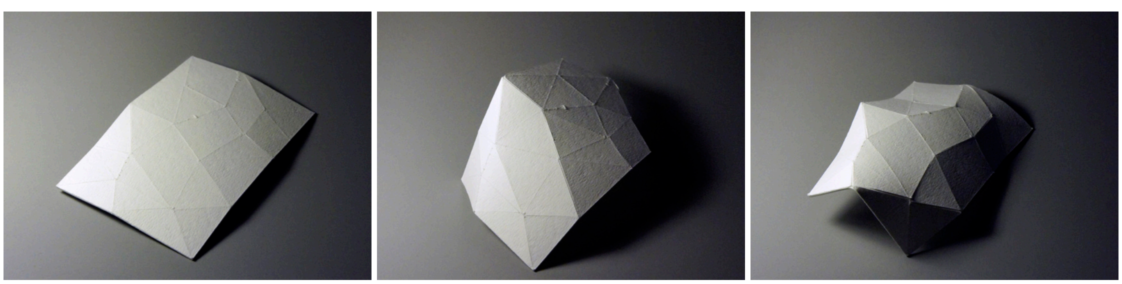


The next step was a failed attempt at generating a transformable surface that could create a foldable enclosure in multiple directions. Because the fold lines generated both triangular and quadrilateral polygons, it was difficult to transform the surface in an equal manner.

Tags: *fold, depth, convex*

c3



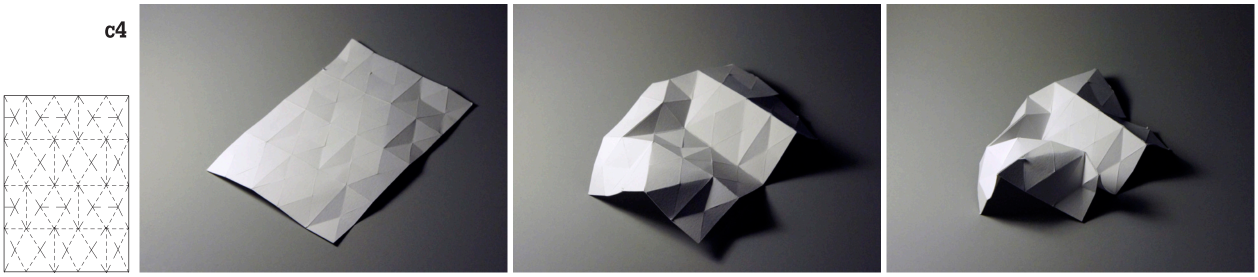


By recognizing the faults of **c2**, and by dividing the surface into pure, triangular polygons, the surface was sharply transformable in multiple directions. By way of its tesselation, it was able to create a variety of angled enclosures. With added ability to reverse the folds, the surface could be manipulated to transform into a variety of concave and convex forms.

Tags: *fold, angle, enclose, convex*

Exploration Set C: triangulated fold

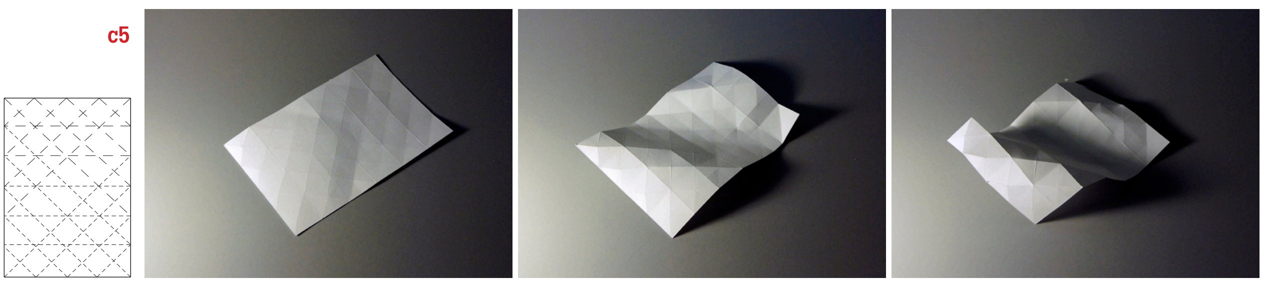
c4



Furthering the results of **c3**, and with reference to the AEGIS Hypo-surface project discussed in the case-study earlier, this model was densely triangulated. It generated a highly transformable surface that could fold in multiple directions, beyond recognition of its initial state. This surface geometry could easily fold to create defining volumes that change to communicate differing spatial experiences.

Tags: *fold, depth, convex, concave*

c5



Almost as a combination of **a4** and **c4**, this surface has a diagonally suggestive convex and concave surface that can undulate in multiple directions. Because it is highly tesselated, the sharp edges of the tesselation become less prominent and increase the capability for smoother, wave-like motions likely to influence movement within a spatial environment.

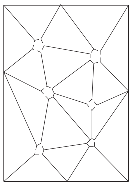
Tags: *fold, depth, convex, concave*

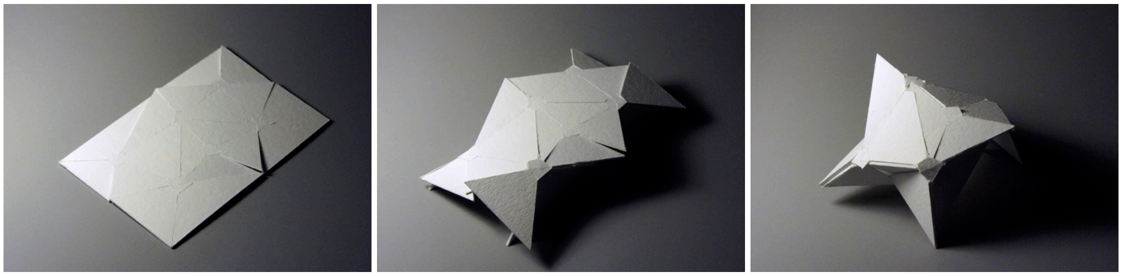
Exploration Set C Summary

This set of explorations revealed the potentialities of folding triangulated surfaces for transformation. It allows a rigidly planar surface to transform into different curvatures that can create complex forms that convex into or concave away from our position in space. The densely triangulated **c5** model will be further explored in a simulation environment that kinetically transforms the surfaces in Thiis-Evensen's spatial definitions with fluid wave-like movement. This simulation could show how fluidity of movement may play a role in affecting our spatial experience.

Exploration Set D: incision

d1

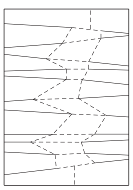


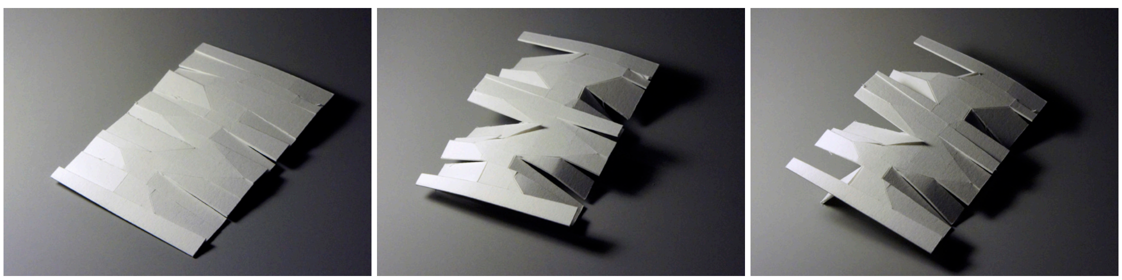


The previous explorations were limited to transformations of a simple and rigid four-sided surface. These following models explore the possible transformations when incisions into the surface were allowed. By taking a triangulated fold surface similar to **c3** and by cutting the fold lines, the surface was able to drastically transform from a two-dimensional plane into what could be perceived as a three-dimensional object.

Tags: *incision, angle, enclose, convex*

d2

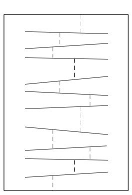


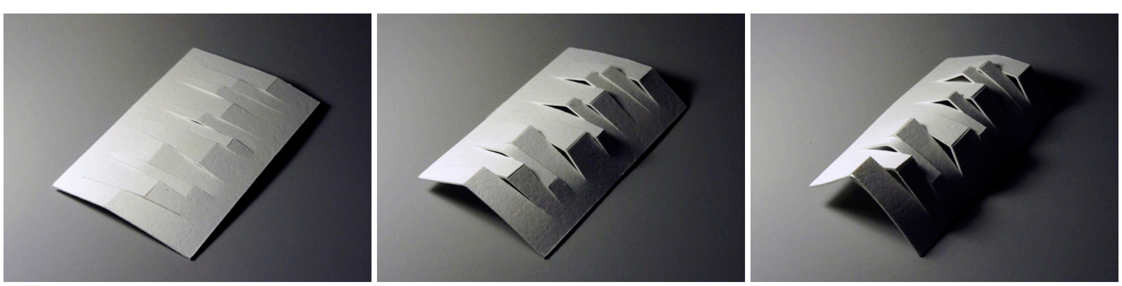


With the dramatic transformation of **d1** in mind, **c1** was revisited and cut variably along the fold lines to create flaps. The intent was to have parts of the perceivable surface lean away from the viewer and flaps organically, similar to Theo Jansen's beach animals. The overall transformation was minimal because the edges of the surface remained in the same position and only the flaps could move due to the rigidity of the material.

Tags: *incision, angle, lean away, flaps*

d3



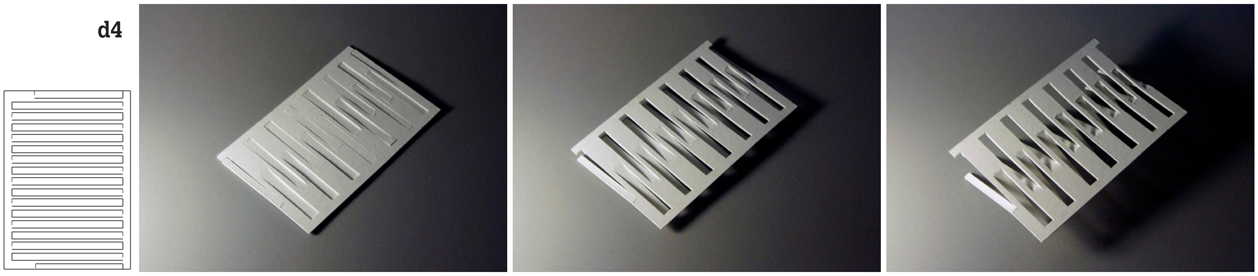


This model was an inverse attempt of **d2** that put the incisions on the interior of the surface. This generated several kinetic apertures that changed size as the surface transformed. These apertures, though small, reveal glimpses of the space hidden behind the surface opposite the viewer, increasing the perceivable depth. This surface eventually led to Exploration Set E and F on apertures.

Tags: *incision, aperture, angle, convex, porosity*

Exploration Set D: incision

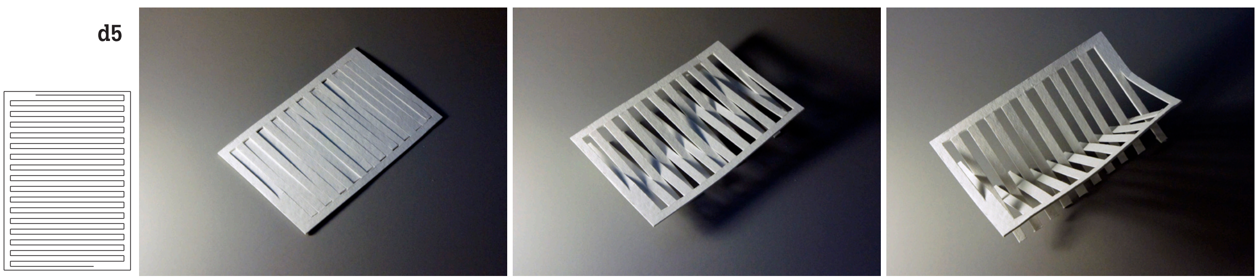
d4



This model had incisions cut in such a way to fold and lean away from the viewer, revealing staggered apertures. It is interesting to note that although there is an increase in the porosity of the surface, the implication is a restrictive one; Because the apertures are relatively thin and adjacent to solid surface areas, it appears more limiting than liberating and tests the extent that porosity plays in a surface.

Tags: *incision, aperture, angle, lean away, porosity*

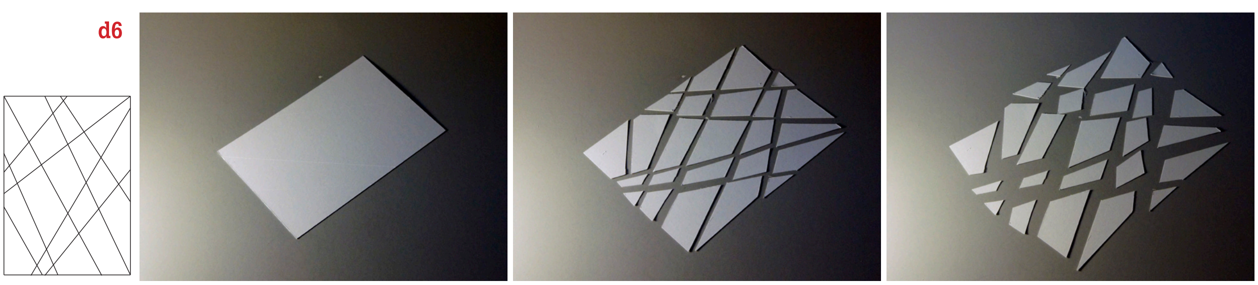
d5



Based on **d4**, this surface attempted to create a transformable surface that almost completely opens up, to understand at which point of the transformation that surface porosity could become liberating. The thin linear apertures still are perceived as restrictive, however, which is a problem more with formal language of the incisions (akin to the foreboding nature of confinement cells or cages) rather than the ratio of aperture to solid surface area.

Tags: *incision, aperture, angle, lean away, porosity*

d6



Influenced again by the AEGIS Hypo-surface project as well as **d5**, this surface is composed of fragmented pieces that expand in scale to become more porous, shifting the focus from the immediately perceivable surface, to what lies beyond it. Rather than a restricted aperture, the expansion of the fragmented pieces test the perception of a dynamic surface and void, and a continually changing figure/ground relationship.

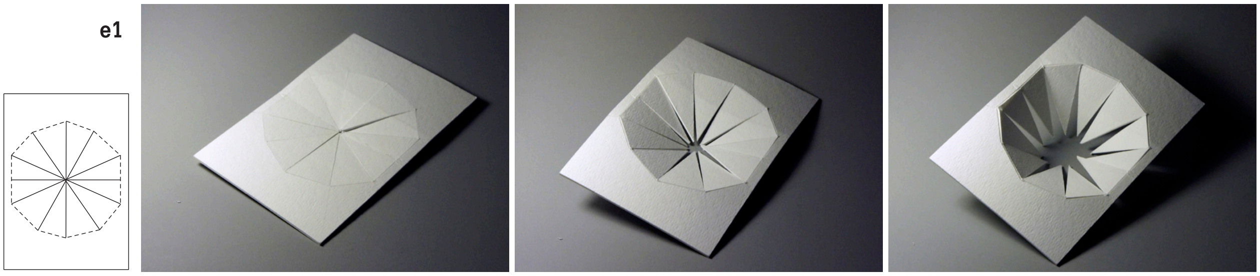
Tags: *incision, scale, fragmented, expand, porosity*

Exploration Set D Summary

By introducing incision into the explorations, the ideas of porosity and aperture are introduced. When one considers the implications of porosity and aperture being motive rather than static, the dynamics of the spatial environment change dramatically. The kinetic apertures created in surfaces like **d3** and **d6** could be explored further by experimenting with the effects it has on perceptions of immediate space and the space beyond the immediate surface. The number and scale of apertures in a transformable surface, as well as its distance from the viewer, could affect the perception of immediate space and space beyond the surface. These explorations, in conjunction with the principles from the Starlight Theater case-study, led to exploring various folding apertures in Exploration Set E.

Exploration Set E: aperture fold

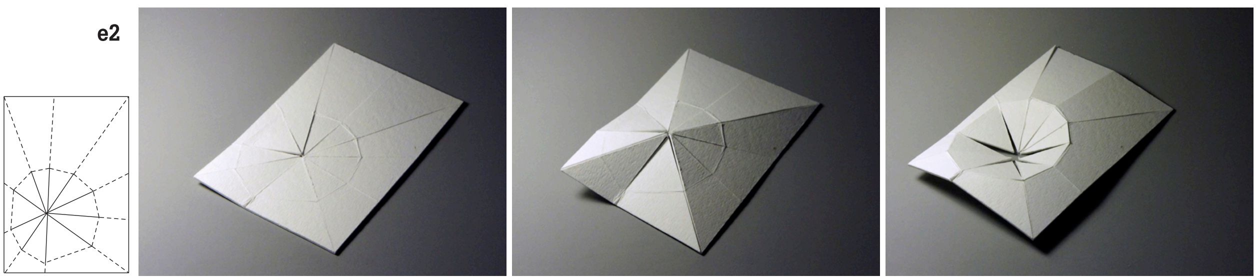
e1



This model represents the idea of transformable aperture influenced by the Bengt Sjostrom Starlight Theater. Through radial cuts from the center of the surface, the transformable aperture can grow from pinhole size to the size of the entire diameter. With a large central aperture that folds away, almost in a concave fashion, this surfaces draws the viewer to focus on the opening and beyond.

Tags: *aperture, depth, incision, fold, concave, porosity*

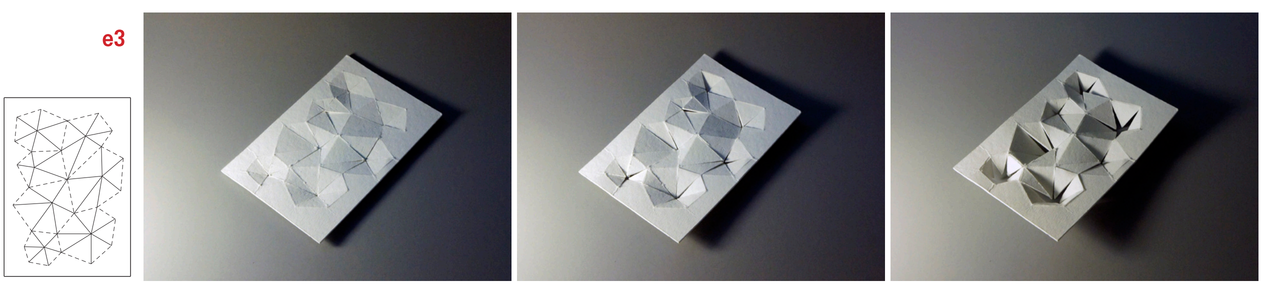
e2



Revising exploration **e1**, this next model offset the aperture and extended fold lines to the whole surface. The fold lines allow the surface around the aperture to convex and appear closer to the viewer, while the opening concaves away. This action shifts the planes of the surface, increasing the perceived depth of the aperture.

Tags: *aperture, depth, incision, fold, convex, concave, porosity*

e3

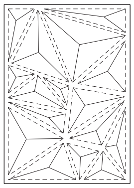


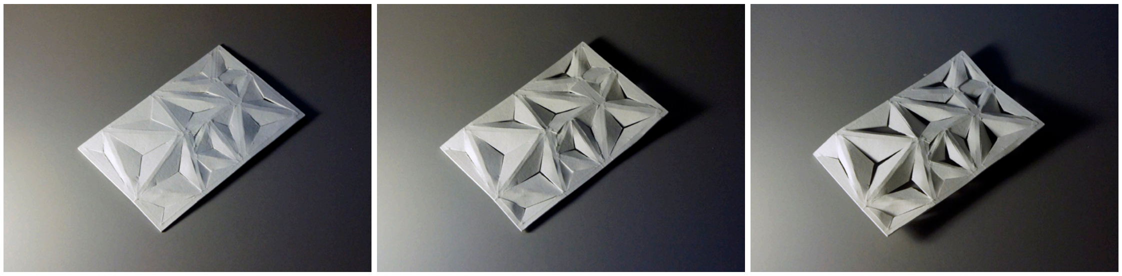
By scaling down and propagating the apertures in **e1** across a single surface, this was an exploration with what occurs with multiple folding apertures. Because the apertures do not cover the whole surface, however, the outline and form of the apertures are the main focus rather than the space beyond, though ones attention could shift as the apertures grow larger.

Tags: *aperture, depth, incision, fold, concave, porosity*

Exploration Set E: aperture fold

e4





This surface is composed of variably-sized triangulated folding apertures assembled across the entire surface. The variation in the fold dimensions creates concaved apertures of different size and depth, which would likely encourage approach towards the surface.

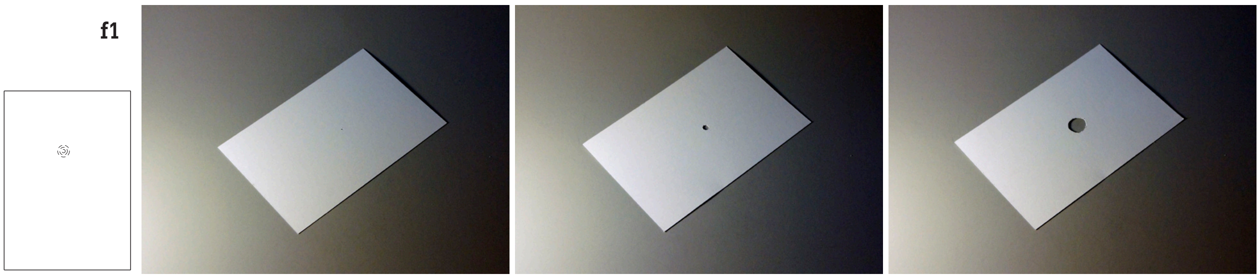
Tags: *aperture, depth, incision, fold, concave, porosity*

Exploration Set E Summary

These explorations were a study on creating folding kinetic apertures on a surface. The apertures are created by surface areas folding out of plane to reveal openings. As these apertures open and close, the visual porosity changes and the viewer perceives a fluctuating permeability of the surface. The transformative properties of surfaces such as **e3** would allow a viewer to experience a visual transition from the immediate vicinity to beyond, almost as if the surface were disintegrating out of view.

Exploration Set F: aperture displace

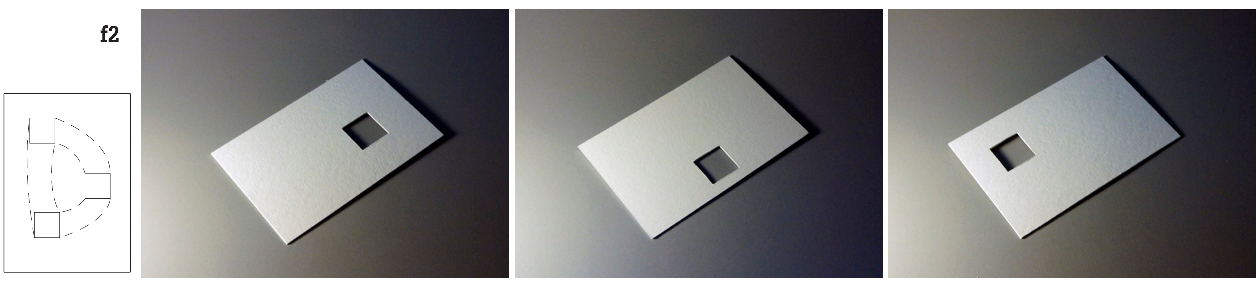
f1



Like a blip on a radar beacon, this simple kinetic aperture generates a dynamic point of interest on the static surface. Though it doesn't achieve the visual porosity seen in Exploration set E, the minimal aperture still manages to provoke an event of itself as it expands and contracts, which would likely draw viewers into that specified point.

Tags: *aperture, expand, contract*

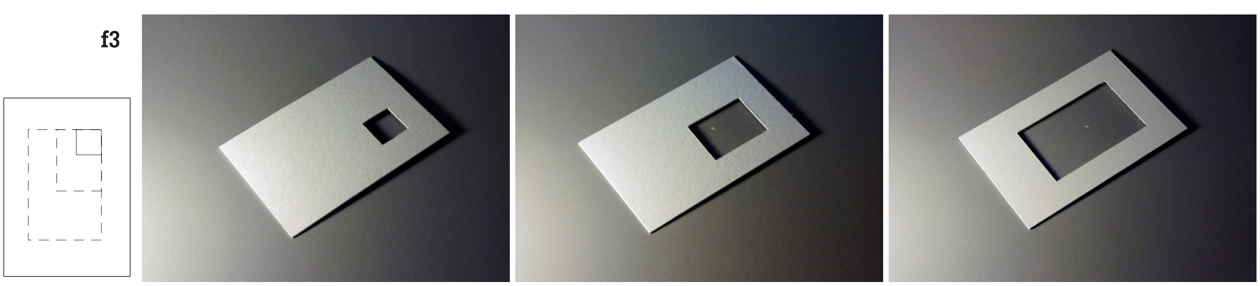
f2



This surface was an attempt to create a motive square aperture that changes its position on the surface, which continually shifts the viewers attention, though the aperture never changes size. If the speed of the aperture motion is high, however, it will no longer be seen as a square but be perceived rather as an elliptical trace of the aperture path.

Tags: *aperture, displace, path*

f3

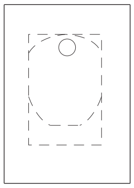


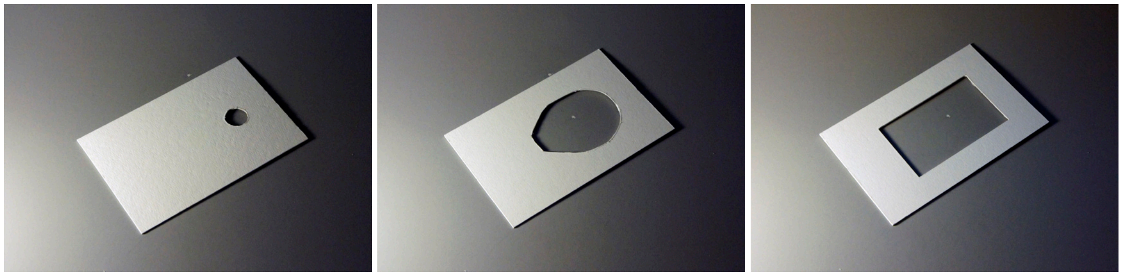
The same aperture in **f2** was then modified with the principles of **f1** to create a kinetic aperture that changes scale. The opening expands to a large area that reveals the space beyond, though still framed by the surface edges.

Tags: *aperture, displace, scale*

Exploration Set F: aperture displace

f4

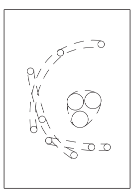


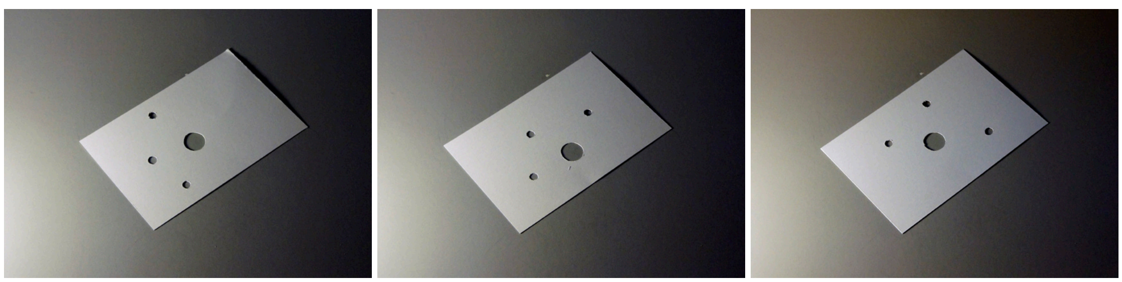


Similar to **f3** except that the initial form of the aperture is a circle rather than a square, this surface experiments with the metamorphosis of the opening and if it would appear as a more fluid-like motion, as opposed to a simple scaling of the aperture. Possibly, with a less rigid kinetic aperture geometry, the surface motion is perceived as less sharp and closer to organic movement.

Tags: *aperture, displace, scale, fluidity*

f5

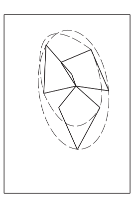


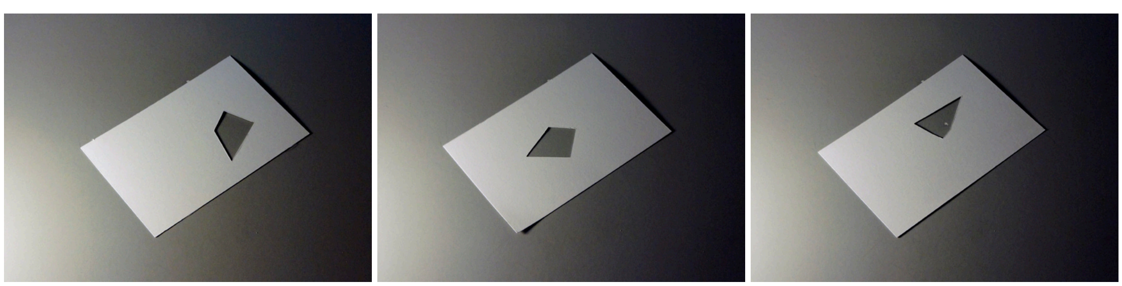


This surface contains four apertures that rotate back and forth. Like **f2**, dependent on the speed of the movement, the path of the apertures quickly supersede the initial aperture forms, as it would begin to be perceived as blending together; the aperture path becomes the new aperture form.

Tags: *aperture, displace, rotate, path*

f6





Using the concept of rotating in **f5**, the polygon aperture in this surface changes its shape while rotating about a single axis, which consistently shifts the apertures form. Again however, the rate of change is very important, as the path of the rotation becomes more dominantly perceived as the speed increases.

Tags: *aperture, displace, rotate, path*

Exploration Set F Summary

The major difficulties with this set of explorations are the limitations of the material. The rigidity of the surface material doesn't easily allow the types of transformations explored in this set, which were made through incisions on separate surfaces, and thus the observations of each transforming surface are inferred. It will require a more malleable material or exploration through computer simulation to test the effects of this set of surfaces. Still, it is advisable to note that in the case of kinetic surface apertures that rapidly shift location, the frequency of the movement as well as the path it takes becomes the determinant factor in how that opening is perceived.

Surface Model Catalog Summary

The explorations generated here are a tiny fragment of the possibilities of differing types of transformable surfaces. One of the limitations of using paper models is that its rigidity restricts particular surface geometries, and thus some of the potential kinetic movement. But the small sampling of surfaces explored here still reveal qualities that prompt further experimentation. Dissecting its properties, each surface was tagged describing the transformation method, concepts of alteration, and with terms related to Thiis-Evensen's spatial definitions. Specific surfaces (namely **b5**, **c5**, **d3**, **d6**, and **e3**) exhibit qualities that will likely provoke discussions against Thiis-Evensen's ideas.

Principles from these surfaces will be applied to Thiis-Evensen's spatial forms in order to ascertain whether his definitions are still applicable in regards to kinetic motion. Using computer generated simulations, we can also explore the application of these kinetic principles free from the material constraints of the paper models.

5 KINETIC SURFACE SIMULATIONS

From the model catalog, select surfaces were chosen to comparatively examine the ability for kinetic principles to affect spatial perception and experience. By applying strategic kinetic manipulations learned from the model studies directly on to surfaces, while retaining Thomas Thiis-Evensen's overall spatial forms, it is clearly revealed that kinetic surfaces are capable of modifying existing spatial fundamentals. Using Rhinoceros 4.0/Grasshopper/V-ray and principles from specific surface models in the previous chapter (namely b5, c5, d3, d6, and e3), these computer-generated simulations experiment with surface conditions in two phases:

PHASE 01

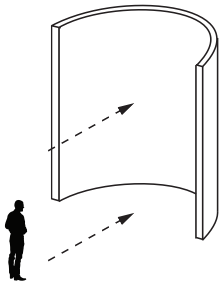
These first four simulations utilize kinetic techniques that provokingly alter the experience of spaces (concave, convex, lean toward, and lean away) as defined by Thiis-Evensen. The spaces retain his fundamental geometry, but the surfaces are modified with kinetic princples.

PHASE 02

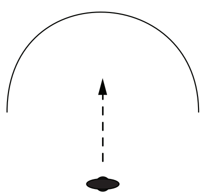
The subsequent four simulations experiment further with kinetic movement particularly in Thiis-Evensen's concave space, as an informative progression toward building a working physical prototype.

PHASE 01: Simulation b5 Concave

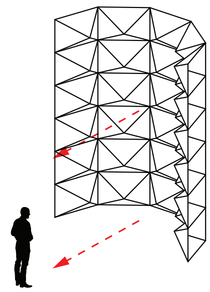
static concave



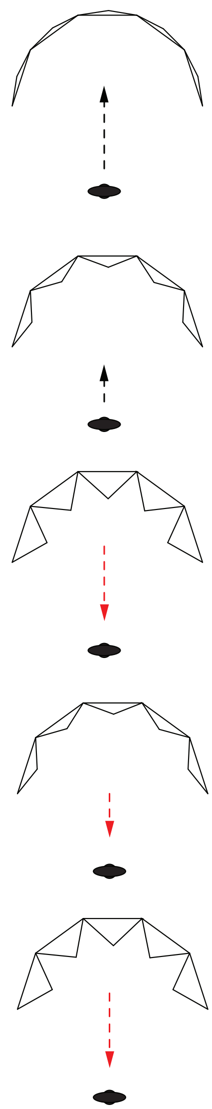
embracing and receiving; yields to our forward movement; pliant; similar feeling to nearness and protection, friendliness and security



kinetic b5 concave

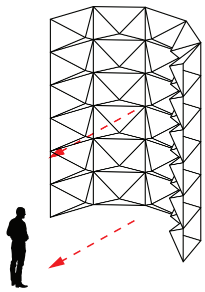


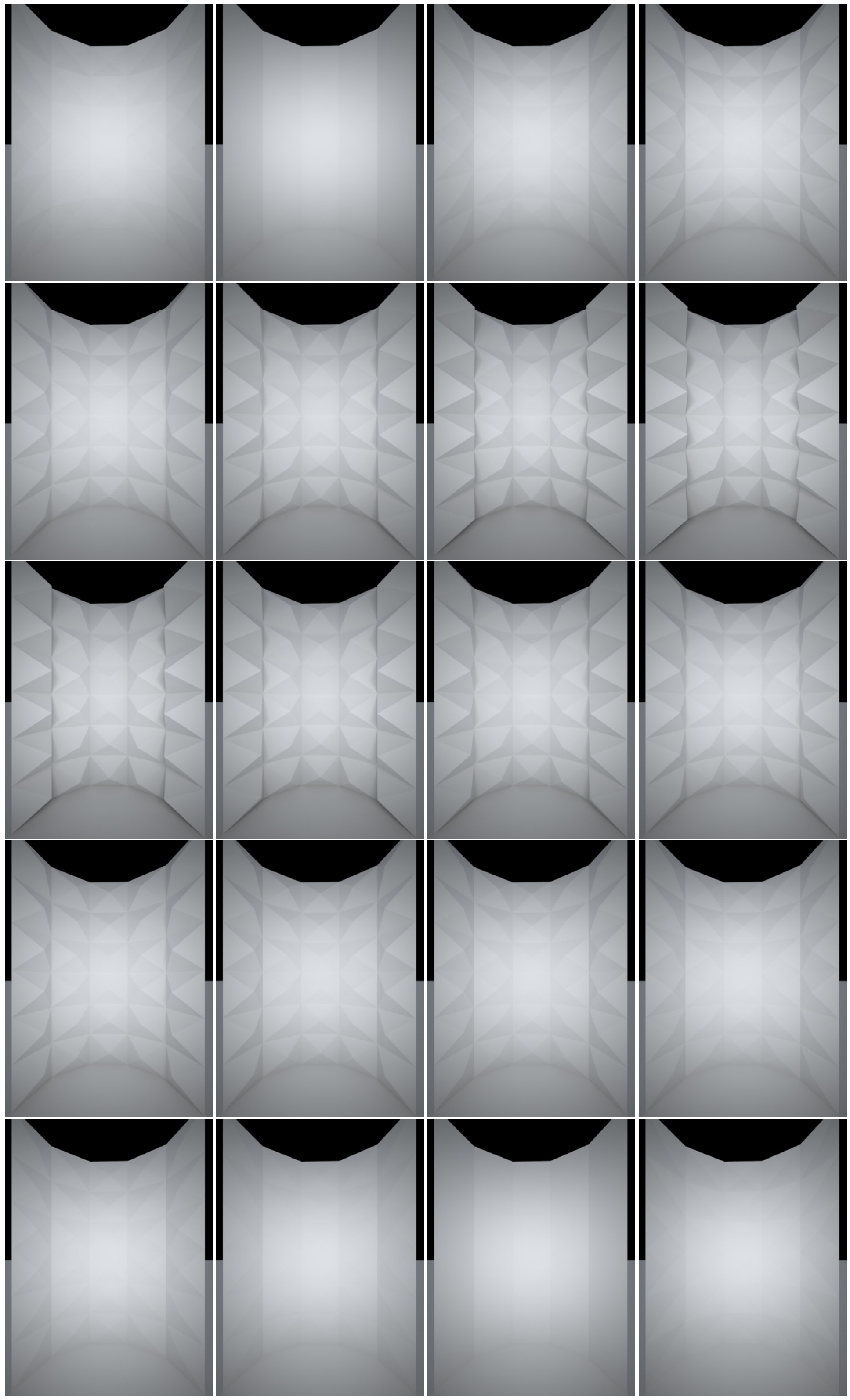
fast outward motion and sharp perceived edges suggest a threatening gesture rather than an embracing one.



a continual agressive outward motion and slow retraction stimulates unease

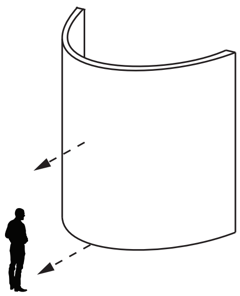
PHASE 01: Simulation b5 Concave



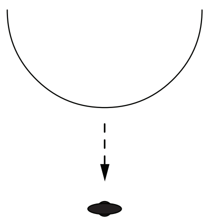


PHASE 01: Simulation d3 Convex

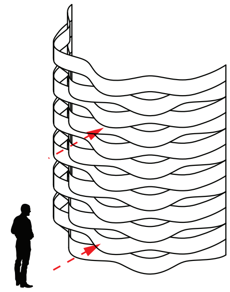
static convex



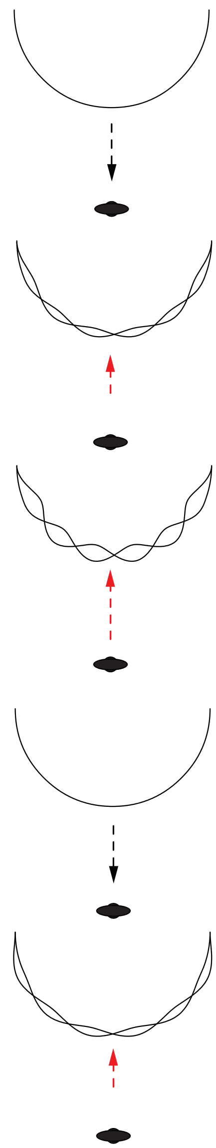
resists our approach; protecting space behind it; solid and concrete thing; outward expansion



kinetic d3 convex

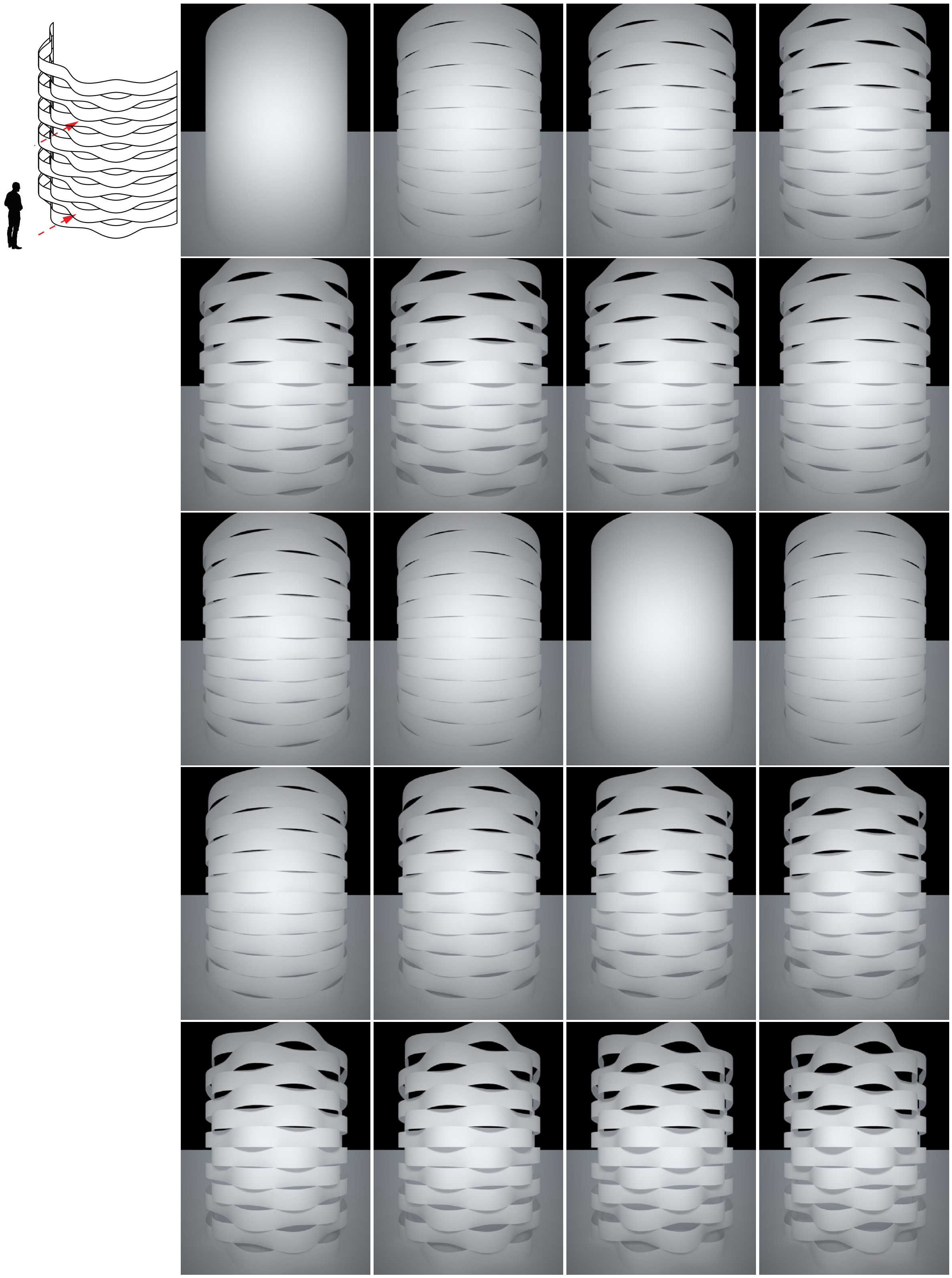


slowly expanding and contracting motion reveals apertures that draw the user towards the surface;



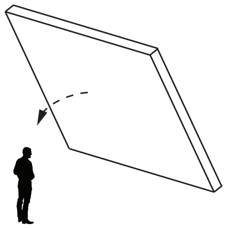
soft curved geometry and slow “breath-like” motion appears organic and inherently captivating, similar in perception to Philip Beesley’s Hylozoic Ground

PHASE 01: Simulation d3 Convex

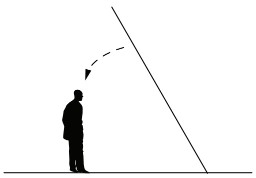


PHASE 01: Simulation d6 Lean Toward

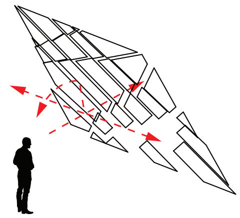
static lean toward



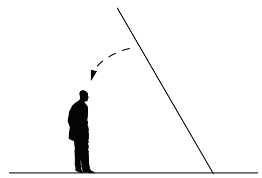
threatening; feel safe only at a certain distance; uncomfortable and dangerous; tense excitement

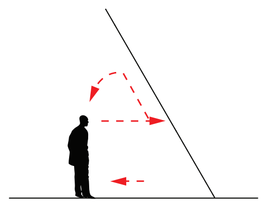


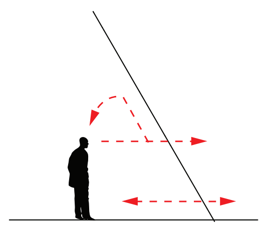
kinetic d6 lean toward



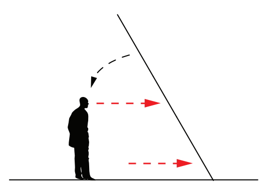
slow, fragmented expansion of surface draws attention outwards and through the surface rather than backwards, though still could be perceived as threatening

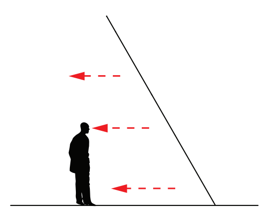






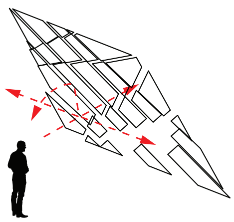
the slow expanding motion allows for visual porosity, which removes the sense of danger

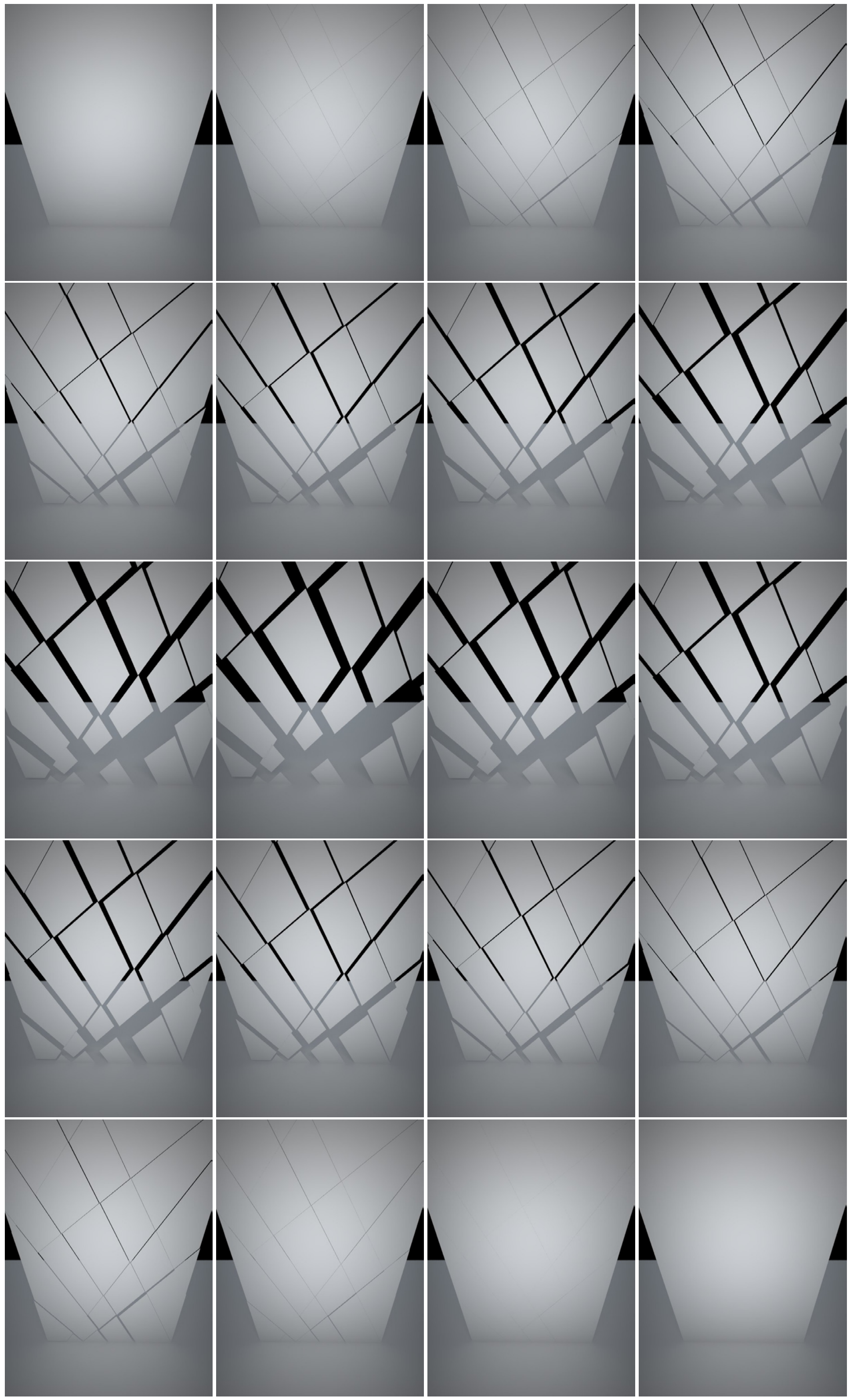




however, when the speed of outward expansion increases, the surface movement is perceived as highly threatening

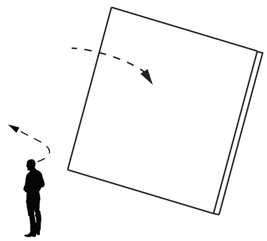
PHASE 01: Simulation d6 Lean Toward



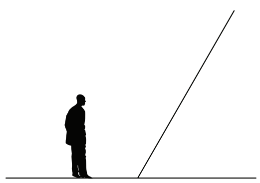


PHASE 01: Simulation e3 Lean Away

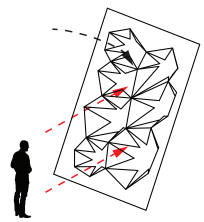
static lean away



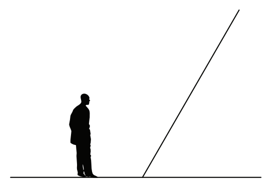
threatens space on opposite side; no longer a concern

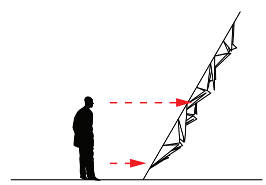


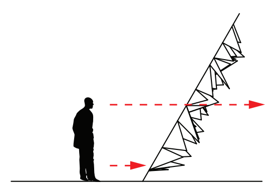
kinetic e3 lean away



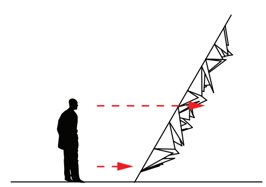
inward folding apertures capture users attention; the pattern and speed of movement stimulate engagement

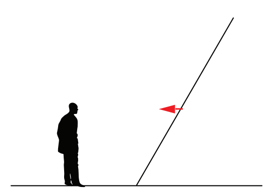






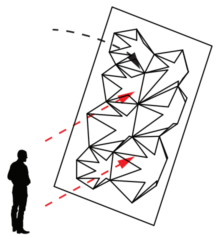
the folds of the aperture happen away from the viewer, giving the surface a visual depth; patterning of aperture movement retain interest

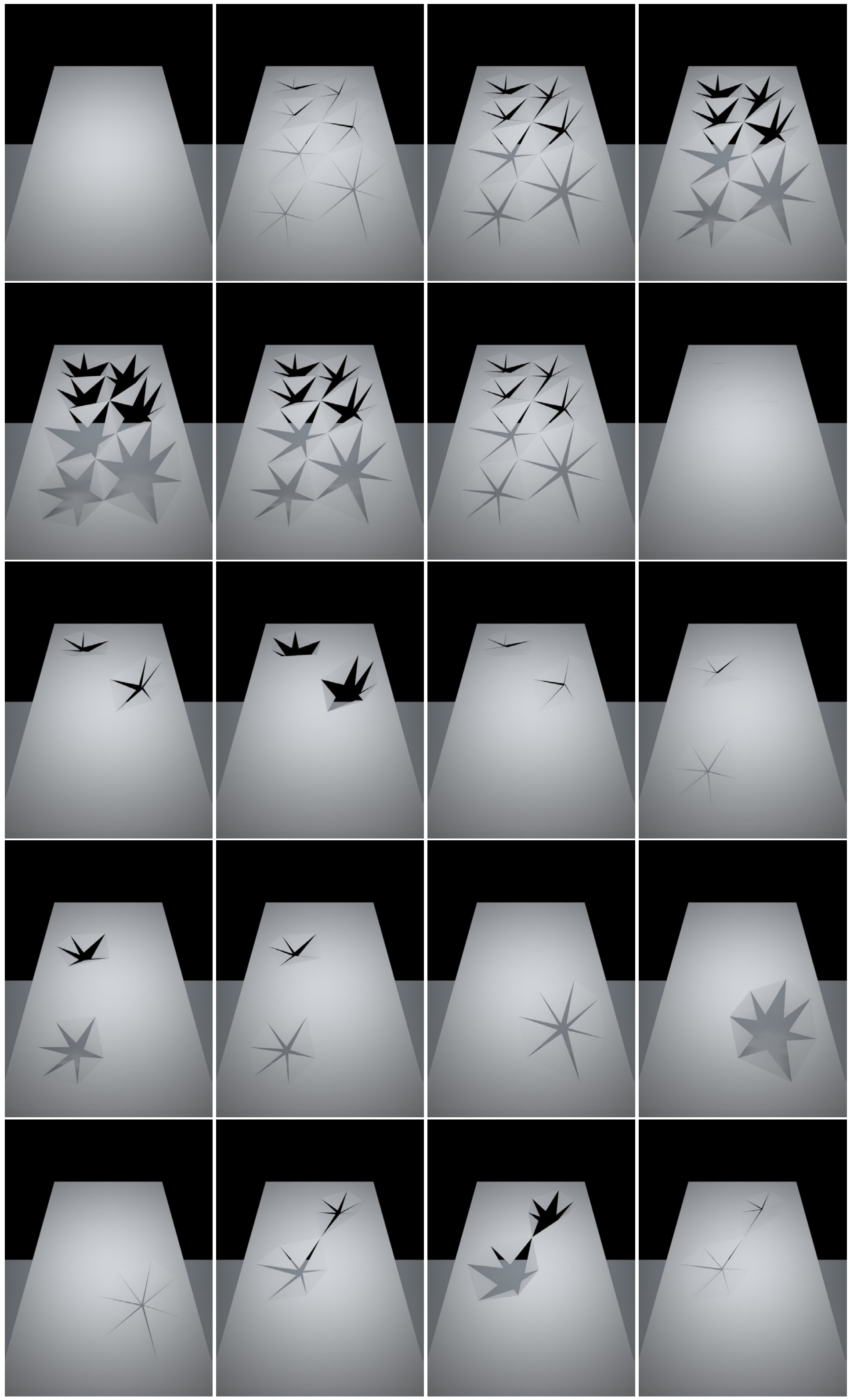




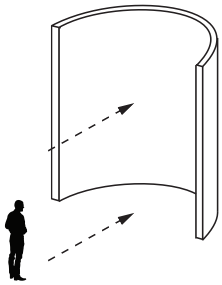
when the apertures close shut it communicates a slight outward expression

PHASE 01: Simulation e3 Lean Away

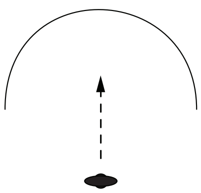




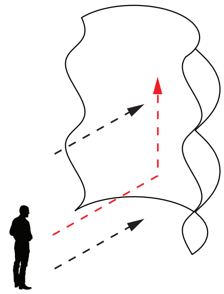
static concave



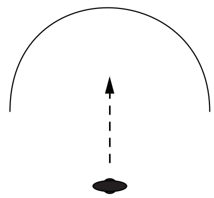
embracing and receiving; yields to our forward movement; pliant; similar feeling to nearness and protection, friendliness and security

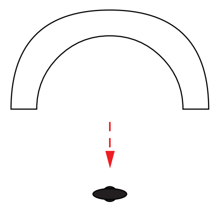


kinetic c5 concave

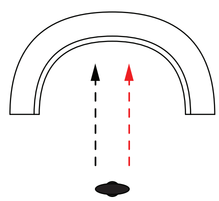


fast wave-like motion naturally draws users attention into and upwards

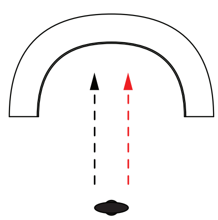


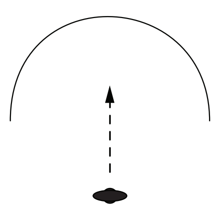


initially, the quick movement instills a sense of tense excitement

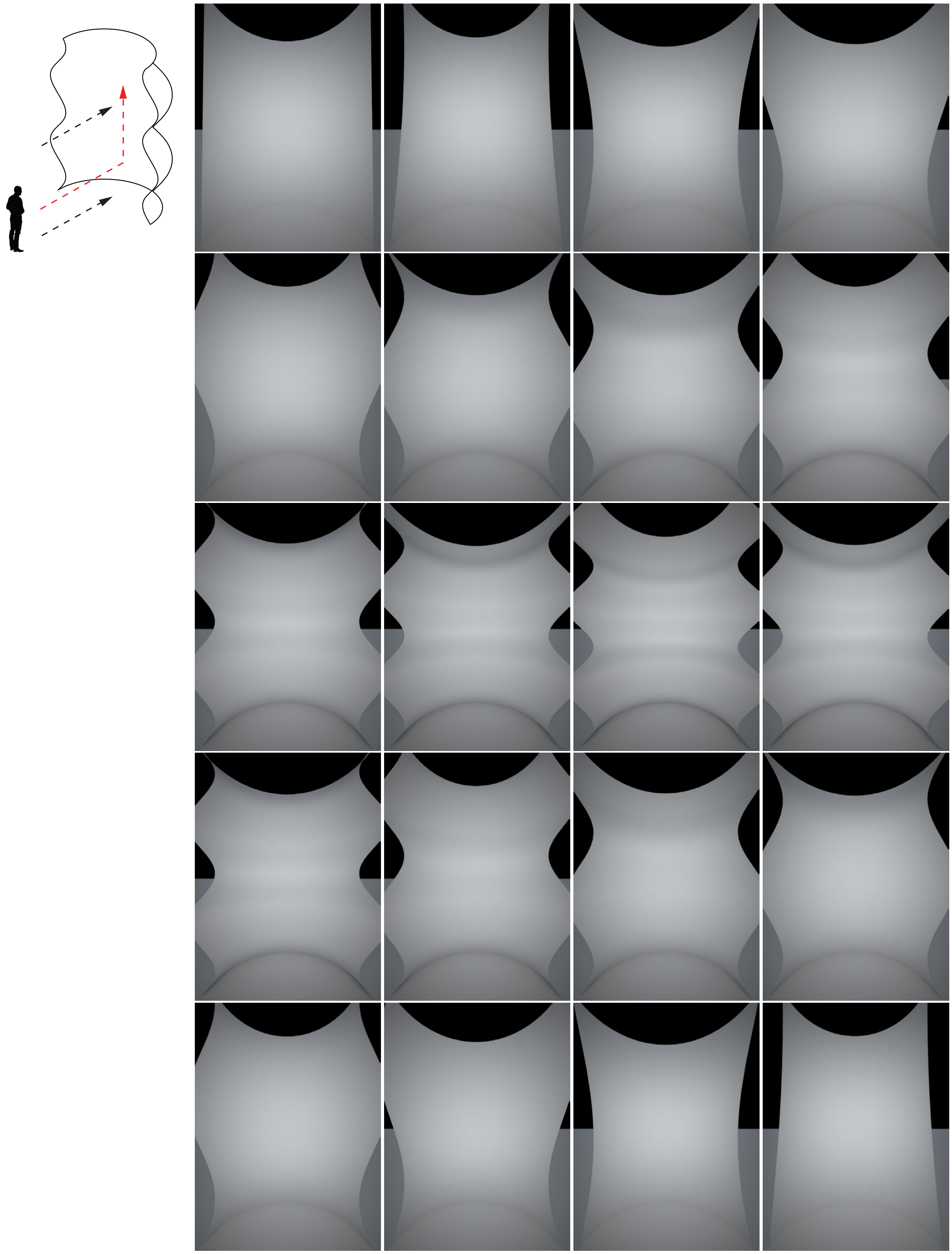


but the fluid wave-like motion enhances the draw into the the concave and upwards as the movement suggests



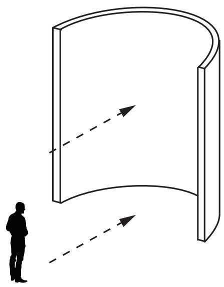


PHASE 02: Simulation c5 Concave

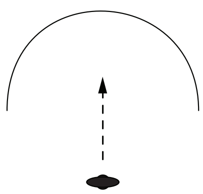


PHASE 02: Simulation d3 Concave

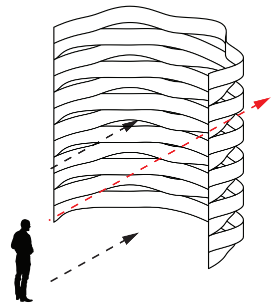
static concave



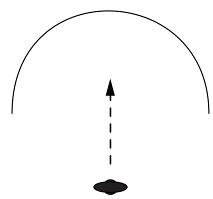
embracing and receiving; yields to our forward movement; pliant; similar feeling to nearness and protection, friendliness and security

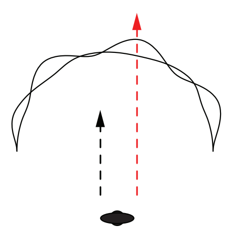


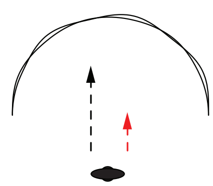
kinetic d3 concave



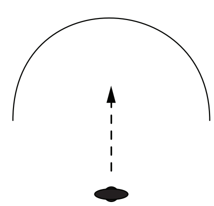
slowly expanding and contracting motion reveals apertures that work in conjunction with the form to draw the user towards the surface

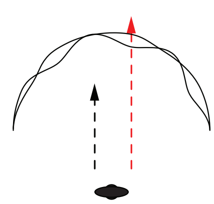




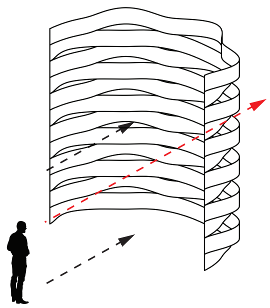


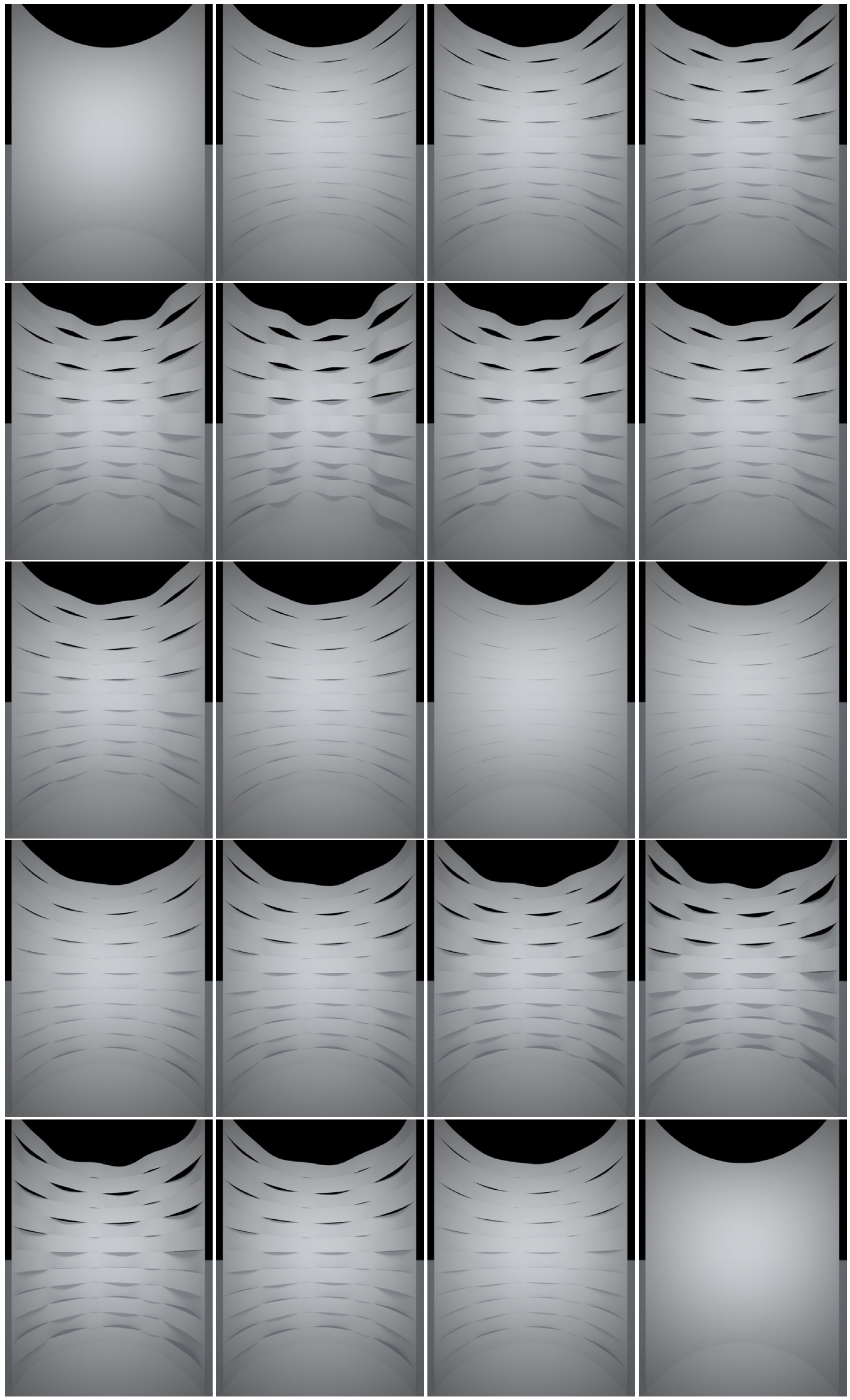
soft curved geometry and slow “breath-like” motion similar to Phase 01 d3 Convex; movement fluctuates the visible porosity





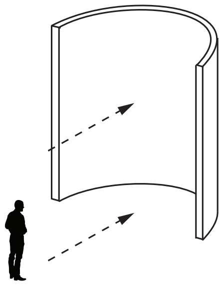
PHASE 02: Simulation d3 Concave



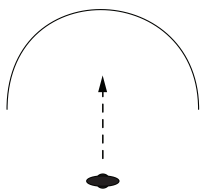


PHASE 02: Simulation d6 Concave

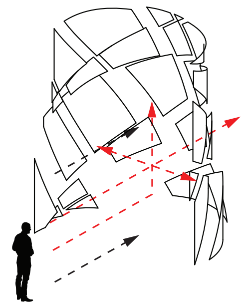
static concave



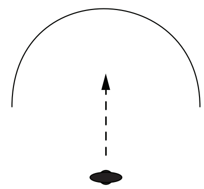
embracing and receiving; yields to our forward movement; pliant; similar feeling to nearness and protection, friendliness and security

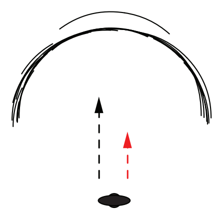


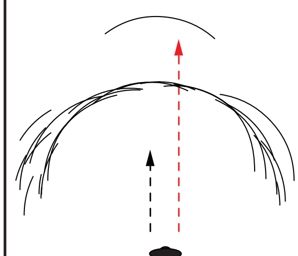
kinetic d6 concave



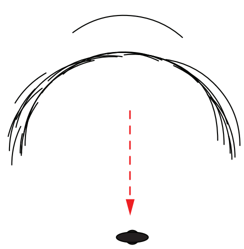
slow fragmented expansion increases the perceivable volume of the concave;



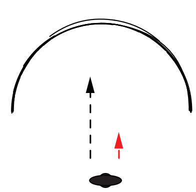




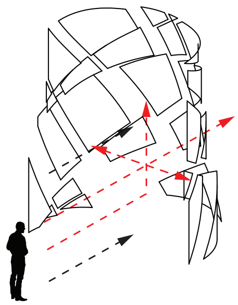
at the greatest surface expansion point, without any movement on their own, the viewer is visually surrounded by the surface

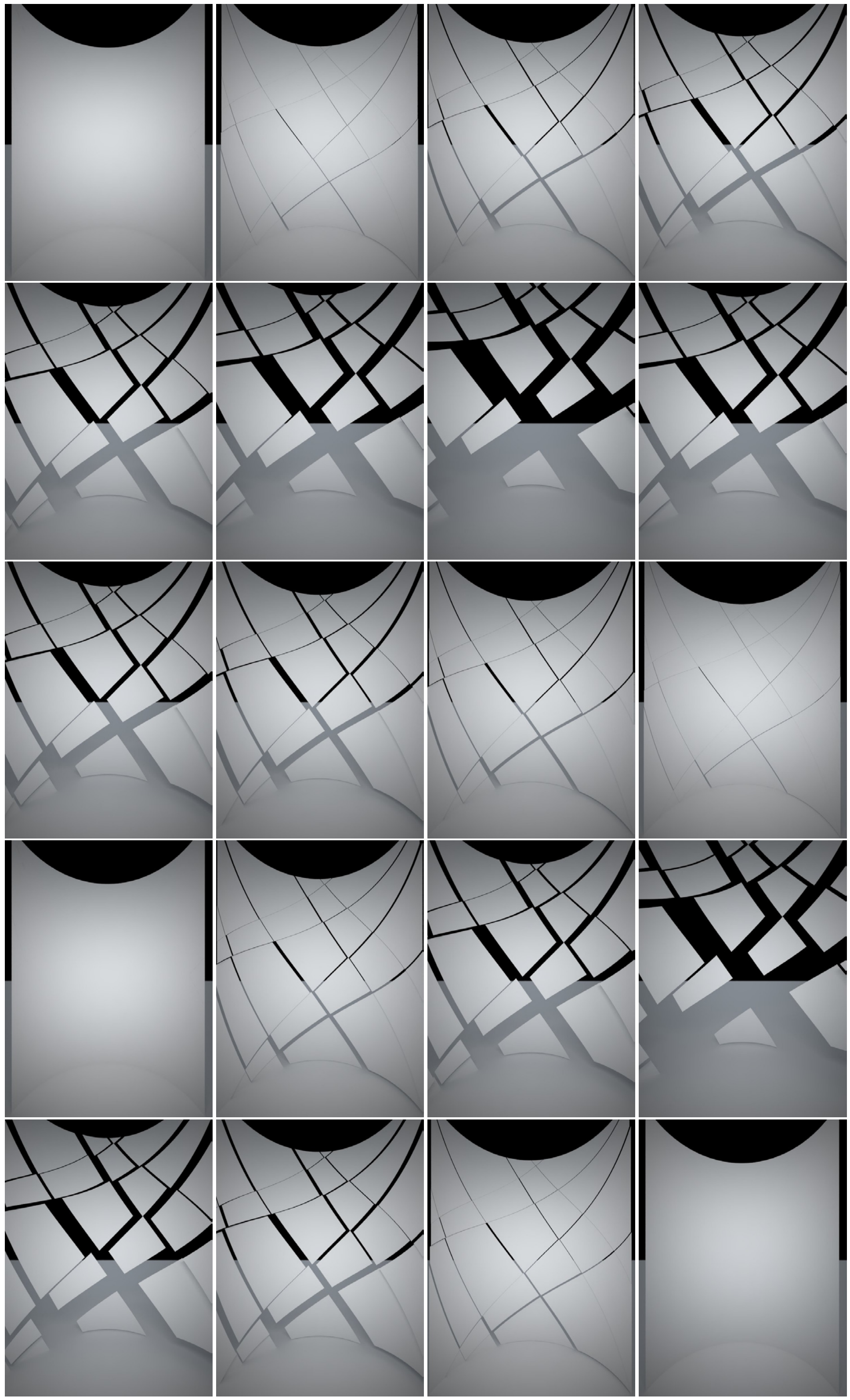


if the rate of expansion is rapid, however, the experience is threatening



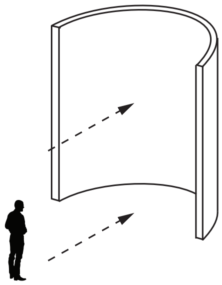
PHASE 02: Simulation d6 Concave



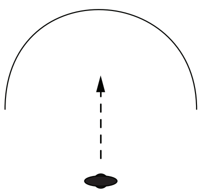


PHASE 02: Simulation e3 Concave

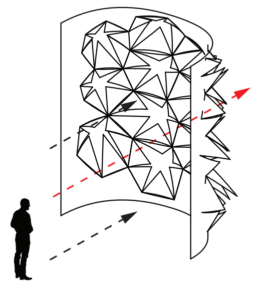
static concave



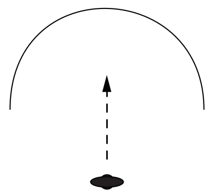
embracing and receiving; yields to our forward movement; pliant; similar feeling to nearness and protection, friendliness and security

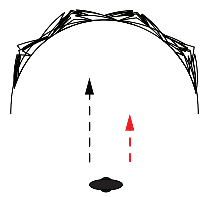


kinetic e3 concave

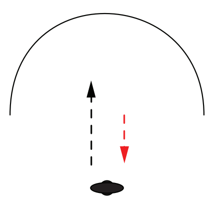


inward folding apertures capture users attention; modifying the speed and degree of aperture opening fluctuates the perception

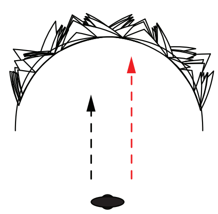


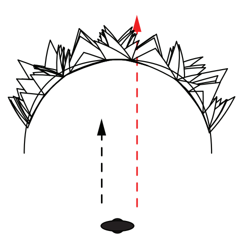


at a 20-degree opening, the apertures create only a slight reveal



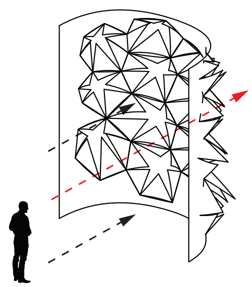
the motion of apertures shutting conveys an outward motion against the user

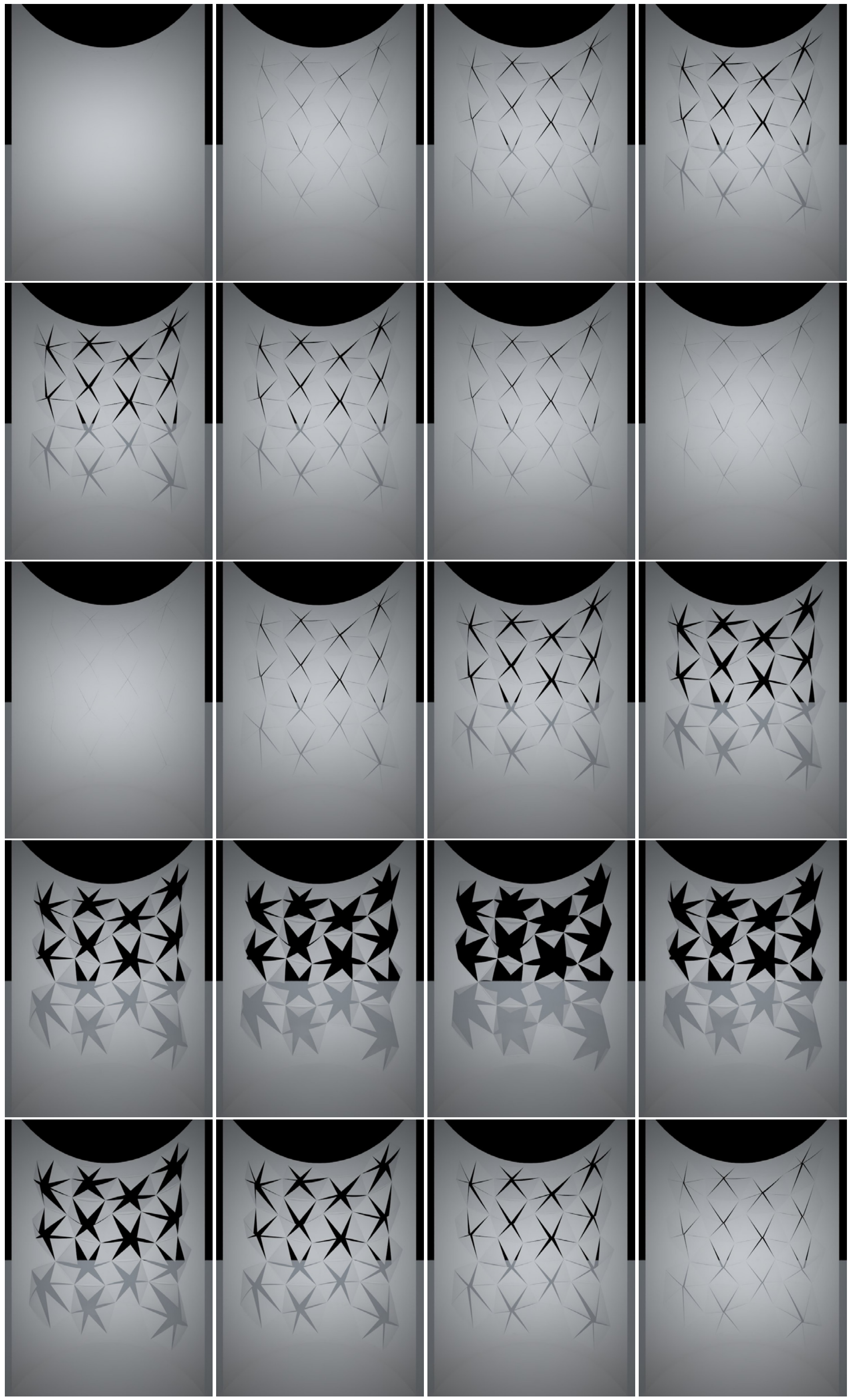




at a 60-degree opening, the apertures reveal much more information beyond the surface, drawing the viewer closer

Phase 02: Simulation e3 Concave





Simulation Summary

Thiis-Evensen's definitions of spatial experience are not entirely applicable when considering the potentialities of kinetic movement. Instead, we need to establish an addendum set of factors that influence our spatial perception and experience. The following set of variables determine, and can be manipulated to alter, ones perception of space:

1) **Frequency**

Slow surface movement is easier for the human eye to perceive and tends to accomodate a comfortable spatial experience, while running the risk of being uninteresting if too slow. Faster movement can be more engaging, but is also harder to perceive as speed increases.

2) **Fluidity**

Smooth, elastic, and natural wave-like movement does not convey a feeling of danger, while sharp and unanticipated motion is quickly perceived as threatening.

3) **Porosity Fluctuation**

A surface that reveals apertures instantly becomes less of a visual obstacle and helps to capture viewers attention towards and through the surface. Utilizing kinetics to adjust the movement of these openings will in turn fluctuate the visual information communicated through the apertures, changing the spatial definition alongside.

4) **Pattern Geometry**

In these models and simulations, the surfaces were subdivided according to the movement required. The edges of the surface subdivisions, if any, can work in conjunction with the movement to define the spatial experience. In the case of Phase 01 Simulation b5, the sharp perceived angles of the pattern geometry, in accord with the agressive outward motion, generate the threatening gesture.

5) **Pattern Density**

If the patterning of the subdivisions is too dense, it can be overwhelming for the user to perceive each part individually. The exception is if the overall movement of the surface allows the subdivisions to be perceived as a whole.

Through the adjustment of these variables, complex and controlled spatial experiences beyond our existing definitions can be achieved.

6 PROTOTYPE PROPOSALS

The computer simulations in the preceding chapter establish the kinetic surface variables that carry the potential to alter ones perception of space, but it is difficult to determine exactly which of these variables have the greatest effect without conducting real-world tests. In order to find out, it is necessary to create physical kinetic surface prototypes designed to be experienced and tested in tangible form. The prototypes should allow testing scenarios in which one of the variables be adjusted while the others remain constant, in order to record and compare the observations.

Ideal Kinetic Surface Prototype

The ideal kinetic surface prototype would allow five testing scenarios, one for each variable, as seen in Table 6.1. It should be designed to allow free adjustment of each variable and also be easily reconfigured to test against specific spatial forms, i.e. Thiis-Evensen's concave, convex, lean toward, lean away, etc.

Fig. 6.1 IDEAL KINETIC SURFACE PROTOTYPE

TESTING SCENARIO	PRIMARY VARIABLE	CONSTANTS
SCENARIO 01	FREQUENCY	FL, PF, PG, PD
SCENARIO 02	FLUIDITY	FR, PF, PG, PD
SCENARIO 03	POROSITY FLUCTIATION	FR, FL, PG, PD
SCENARIO 04	PATTERN GEOMETRY	FR, FL, PF, PD
SCENARIO 05	PATTERN DENSITY	FR, FL, PF, PG

FR = FREQUENCY; FL = FLUIDITY; PF = POROSITY FLUCTUATION; PG = PATTERN GEOMETRY; PD = PATTERN DENSITY

However, considering the endless variation of spatial forms, the reality of available materials and their properties, and the mechanisms to generate movement, it may be difficult to create this ideal kinetic surface prototype that satisfies all the criteria. Instead, it may prove easier to generate a number of different prototypes that test only a few of these variables. Creating numerous prototypes of different types can also assist in discovering nuances in the relationship between kinetic surfaces and spatial experience.

Prototype 01 - Kinetic Concave: ZF-CC-11100

This first prototype, called Kinetic Concave, allows testing of three scenarios: Frequency, Fluidity, and Porosity Fluctuation. Also known as ZF-CC-11100 (zigzag fold + concave + scenarios 01, 02, 03), this prototype draws on concepts of folding planes and apertures from the surface model catalog. Due to the limitations of rigid planar material and the number of servos available, varying pattern geometry and pattern density (scenarios 04 and 05) are not possible with this prototype. Still, the computer-controlled servos allow a wide range of different surface movements to be programmed related to the first three scenarios.

Fig 6.2 PROTOTYPE 01 - KINETIC CONCAVE: ZF-CC-11100

TESTING SCENARIO	PRIMARY VARIABLE	CONSTANTS	INITIAL COMMENTS
SCENARIO 01	FREQUENCY	FL, PF, PG, PD	SERVO SPEED AND DELAY
SCENARIO 02	FLUIDITY	FR, PF, PG, PD	SERVO FIRING ORDER AND TIMING
SCENARIO 03	POROSITY FLUCTUATION	FR, FL, PG, PD	0" to 6" HORIZONTAL OPEN-INGS
SCENARIO 04	PATTERN GEOMETRY	FR, FL, PF, PD	TRIANGULATED
SCENARIO 05	PATTERN DENSITY	FR, FL, PF, PG	28 SUBDIVISIONS

FR = FREQUENCY; FL = FLUIDITY; PF = POROSITY FLUCTUATION; PG = PATTERN GEOMETRY; PD = PATTERN DENSITY

The 4' wide by 2' high surface forms a concave space, which viewers should feel embracing and receiving in its static state, according to Thiis-Evensen. Using an Arduino microcontroller and 14 servos, surface control points can be displaced linearly approximately 6 inches. Each servo controls movement of two triangulated-surface subdivisions (28 total). By way of adjusting the code (Arduino sketch) to control servo speed, delay, and firing order, the movement can move uniformly or sporadically, depending on the intent of the motion. The reprogrammable nature of the prototype allows for a wide range of experiments that can test the amplification, contradiction, or convolution of the spatial experience the kinetic surface provides.

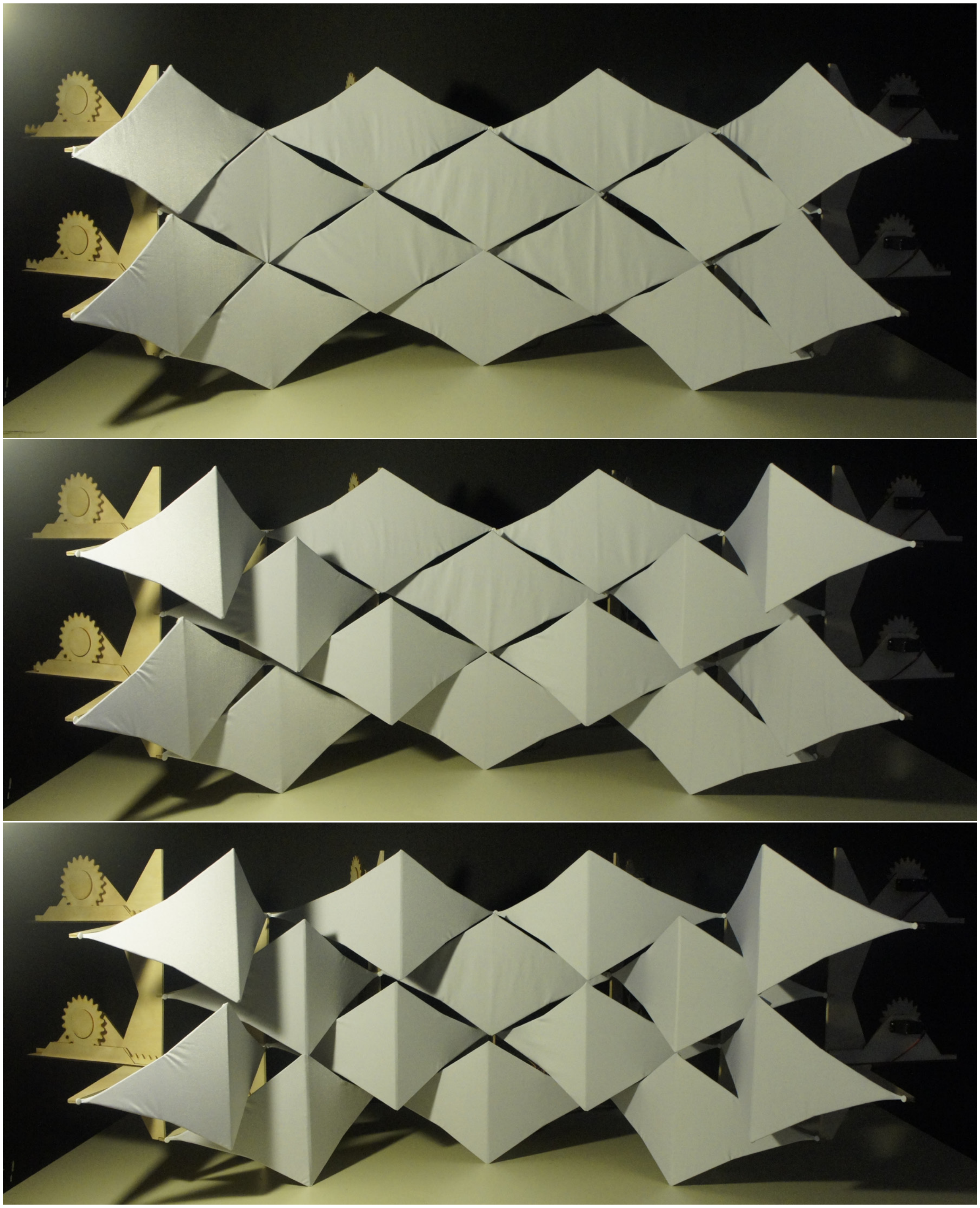


Fig 6.3 Prototype 01 varied positions.

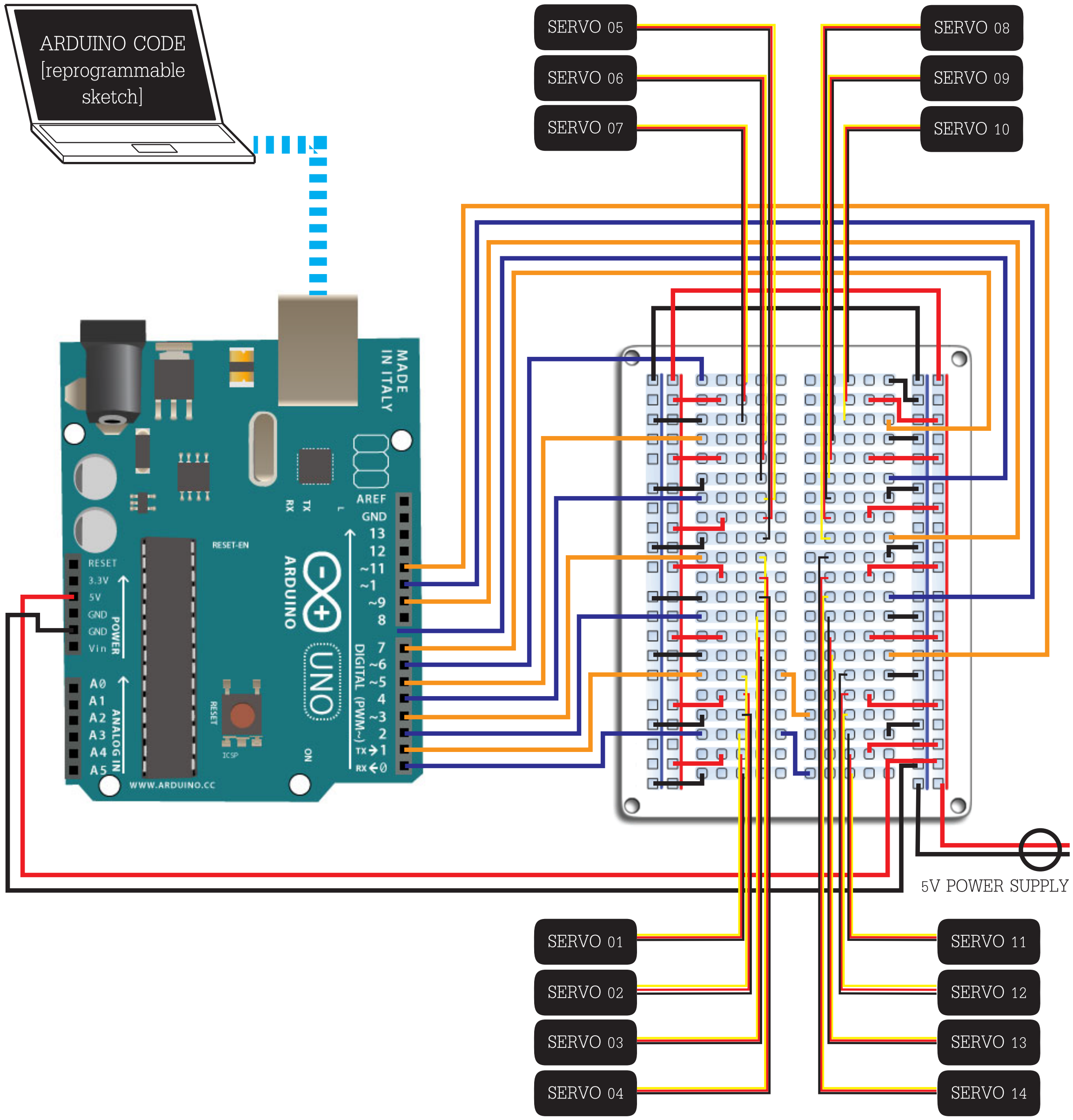


Fig 6.4 Wiring schematic.

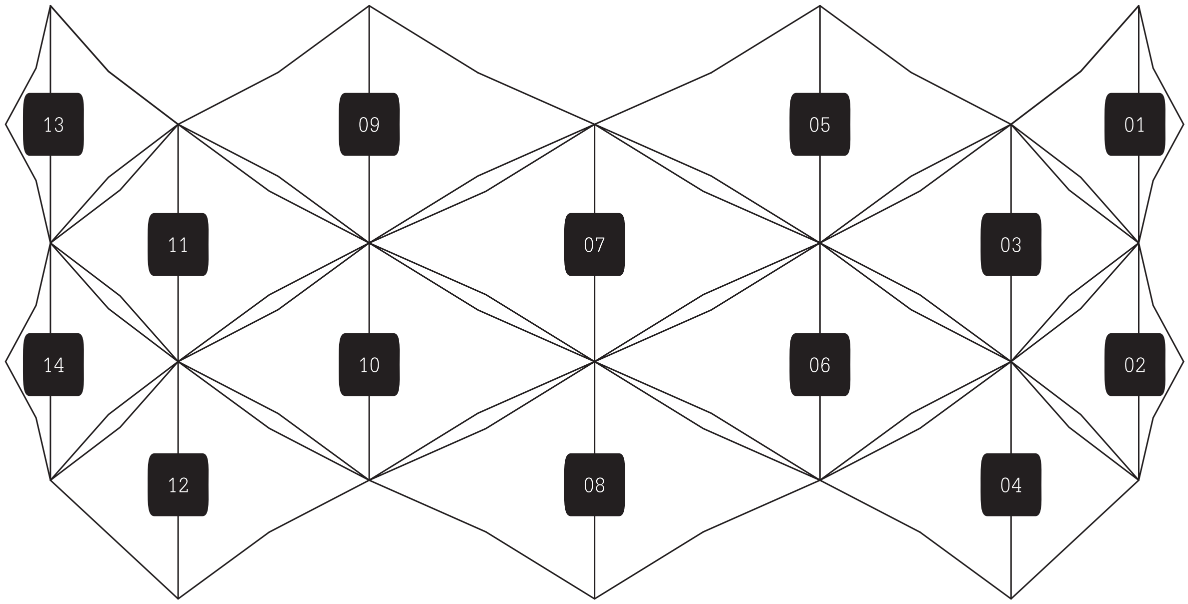
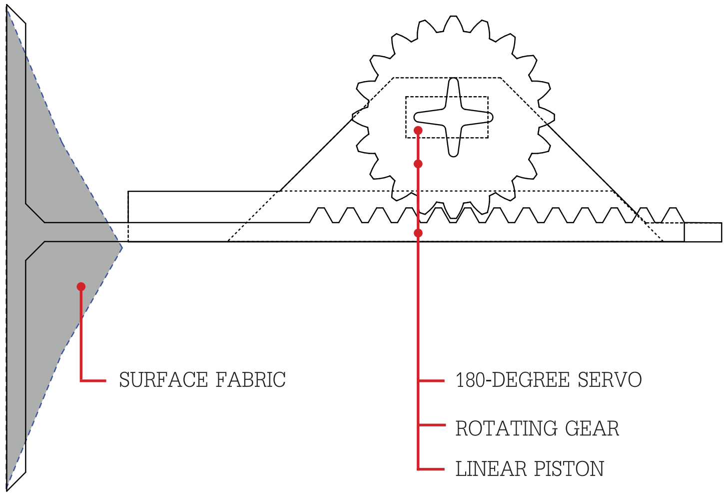


Fig 6.5 Surface Elevation showing servo placement



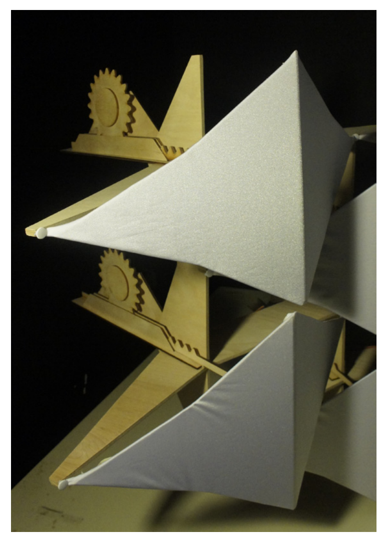


Fig 6.6 and 6.7 Surface subdivision details

While this research does not delve directly into the data results of testing the scenarios in this initial prototype, it is intended to be utilized as a tool for future research. The lessons learned and limitations discovered when testing this system will perhaps inform an array of prototypical versions of kinetic surfaces that can ultimately determine which kinetic variable has the greatest potential effect on our spatial experiences.

7 CONCLUSION

The results of this research support that the understanding of the relationship between spatial experiences and kinetic surfaces is still in its infancy. By no means do my explorations conclude the study regarding the spatial experience of kinetic environments, but rather, it provides impetus for furthering this architectural discussion based on this newly established framework. It also supports the idea that spatial experience extends beyond what is achievable with static built environments; Utilizing kinetic surfaces can create environments that are as transformable, motive, responsive and adaptable as humans. As the design of kinetic surfaces in our built environment continually progress with technological advancement, the potentialities should be continually tested and explored. Still, despite the open-ended range of the spatial possibilities of kinetic surfaces, this research has successfully answered the following questions:

Do kinetic surfaces modify ones' perception of space?

Yes. We see in chapter 2 that motion is the strongest visual appeal to attention as it implies a change in the conditions of the environment, and change may require reaction. Kinetic surfaces that define our environments, then, inherently command our attention. The movement of surfaces adds another layer to our spatial perception, whose importance is akin to surface geometry and materiality. As such, applying kinetic principles can work in accord or against the geometry and materiality of a surface, creating extremely expressive or even contradictory spatial experiences, depending on the strategy employed. Our spatial experience of these kinetic environments, though still relying on the surrounding perceivable surfaces, also depends largely on our assessment of the type of movement involved.

Do existing spatial definitions still apply when considering the movement of kinetic surfaces?

No. The explorations in chapter 5 show that existing definitions of spatial experience, Thiis-Evensen's in particular, are not applicable when considering the potentialities of kinetic movement. Utilizing a transforming surface (as seen in chapter 4) can create a variety of spatial relationships that continually modify ones' perception as movement occurs. For example, movement can be structured to counteract the existing perception of space as in the B5 Concave simulation, where the aggressive surface movement works to contradict the typical experience of the concave space.

What are the variables of kinetic surfaces that affect spatial experience?

Frequency, Fluidity, Porosity Fluctuation, Pattern Geometry, and **Pattern Density.** These variables were established through the case-study analyses in Chapter 3 and computer generated simulations in Chapter 5. Controlling these variables has the potential to yield interesting results that can amplify, contradict, or convolute one's spatial experience.

It will take many more experiments to truly determine which of these variables factor the most in our perception of kinetic surfaces. The prototype proposals offer a guide to an approach towards these future experiments. It can be argued that only then can we fully understand the implications of designing thoughtful and innovative kinetic environments. Ultimately, it is my hope that this research stimulates attention towards a non-static type of architecture. The research encourages designers to consider continuing the design-research oriented explorations and investigations of kinetic surfaces in order to create built environments that understand and react to the user, as well as transform and adapt to our rapidly changing human condition, rather than strictly focusing on rigidly-immovable spaces designed for permanence. These kinetic environments can be designed achieve more efficient function, aesthetics, and sustainability. But most importantly, these environments should openly express the importance of relationships between user and space, and ultimately provide a dynamically influential and truly enriching spatial experience befitting of our own kinetic nature.

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Fig.